Filtered Containment Venting System Designs

Development

Features

Qualification

Applications

Bernd Eckardt, Norbert Losch

NRC Meeting on Containment Venting Systems

Rockville, July 12th, 2012

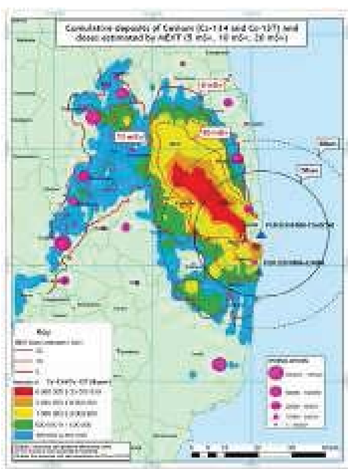
AREVA Safety Alliance

Filtered Containement Venting Systems
Agenda

- **General**
  - **Objectives**
  - **General Requirements**
  - **System Overview**
- **Process Development Steps**
  - **Venting Technologies (historical and technology orientated)**
    - Scrubbers, filters, sorbents media, standard and new liquid agents
    - Test results technology related
- **New Developments**
  - **High Speed Sliding Pressure Venting ^{Plus}**
  - **Improved Organic Iodine Retention**
- **Qualification (JAVA test / International test / JAVA ^{Plus})**
- **Installations Examples**

Severe Accident Management
Objective of Filtered Containment Venting

- Prevent loss of containment integrity as a result of over-pressurization
- Provide reliable venting function for containment pressure control (safety valve function), to minimize impact for the environment and avoid long term land contamination



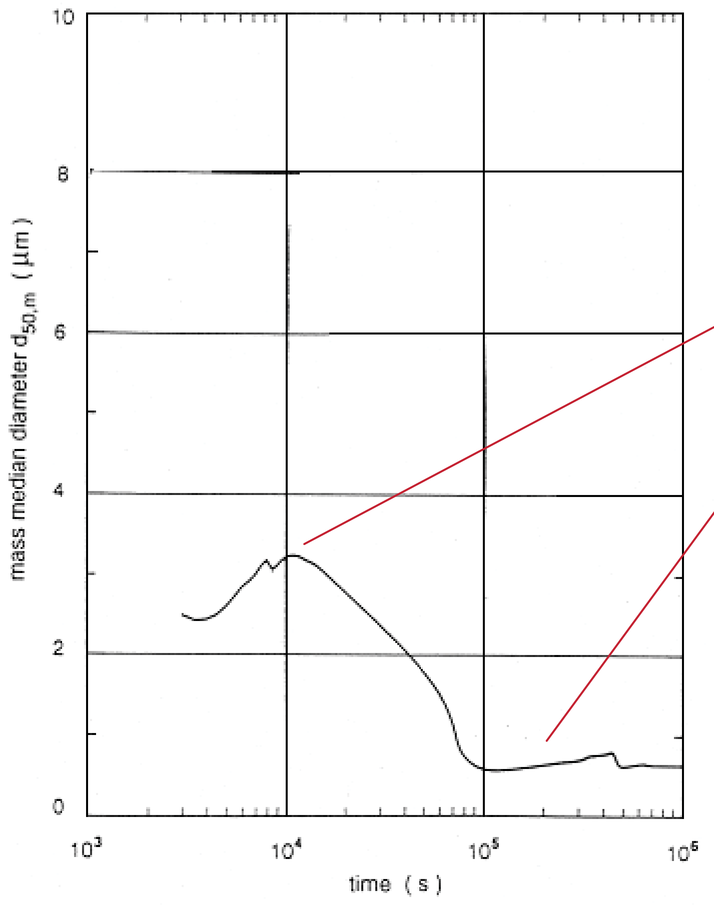
Reference: **Institut de Radioprotection et de Surete Nucleaire (IRSN)**
Report DRPH / 2011-10

<table>
<tr><td>Deposits of caesium (137 + 134) (Source MEXT)</td><td>> 300,000 Bq/m^2</td><td>> 600,000 Bq/m^2</td><td>> 1 million Bq/m^2</td><td>> 3 millions Bq/m^2</td><td>6 - 30 millions Bq/m^2</td></tr>
<tr><td>External dose at 10 years (70 mSv by MBq/m^2)</td><td>> 19 mSv</td><td>> 38 mSv</td><td>> 63 mSv</td><td>> 190 mSv</td><td>380 - 1,900 mSv</td></tr>
<tr><td>External lifetime dose (70 years) (160 mSv par MBq/m^2)</td><td>> 41 mSv</td><td>> 82 mSv</td><td>> 136 mSv</td><td>> 408 mSv</td><td>816 - 4,080 mSv</td></tr>
<tr><td rowspan="3">Affected population (excluded the no-entry zone)</td><td rowspan="3">292,000</td><td colspan="4">69,400</td></tr>
<tr><td rowspan="2">43,000</td><td colspan="3">26,400</td></tr>
<tr><td>21,100</td><td>3,100</td><td>2,200</td></tr>
</table>

Relevant filtered venting potential identified
for minimizing off-site long-term dose issues

Principle
Aerosol distribution during a Severe Accident (SA)

Mass Median Diameter of Aerosols in the Containment as a Function of Time (NAUA calculation for PWR)



PWR Dry Containment:

Large and fine aerosols (d < 0.5µm] are generated during a SA

-large aerosols in early accident phase

- fine aerosols mid term

Due to sedimentation the aerosols concentrations & diameter drops, preferable fine aerosols remain airborne

BWR specific :

-Wet well:

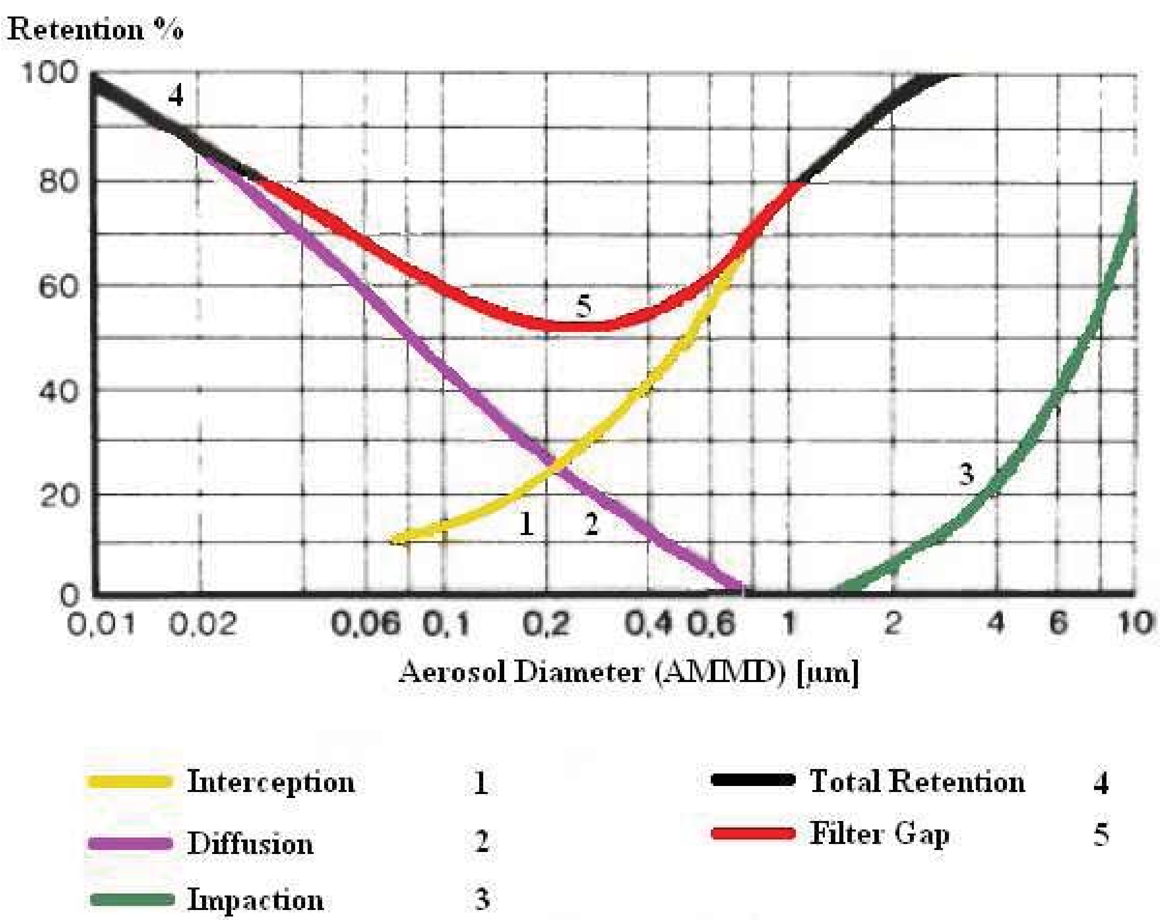
Down stream wet well fine aerosol fraction will be dominant, because

-more efficient scrubbing of larger aerosols

and

-comparable low retention of fine aerosol fraction

„Filter Gap“



Depending on the particle diameter the retention efficiency varies.

Every filter has a filter gap (lower removal efficiencies for particles of a particular size)

Process Requirements

- **Robust in terms of**
  - Aerosol quantities
  - Aerosol size distribution
  - Types of aerosols (hygroscopic, non-hydroscopic, etc.)
  - Decay heat transfer
- **DF´s verified under the real operating conditions**
- **Following the design principles:**
  - Avoidance any burnable, organic material in the process
  - Use of metallic or ceramic materials
- **Avoidance of any „cliff edge" effect, e.g.**
  - Scrubber foaming
  - Filter clogging

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Process Requirements

- **Overload capacity**
  - Filtration efficiency shall be maintained, e.g. late venting at 2 Pd (Pd= Design Pressure Containment) which results in doubling of mass flow rate/velocities

- **Focus on S.A. process qualification**
  - Independent, international, third party qualification on a large scale basis
  - Qualification of full operating range, as
    pressure (e.g. as sliding pressure for scrubbers and in-containment filters), velocities, aerosol types
  - Emphasize qualification and minimize / delete requirements on nuclear pressure code requirements for beyond design accidents

» **See main result of all international, independent, third party testing incl. significant findings!**

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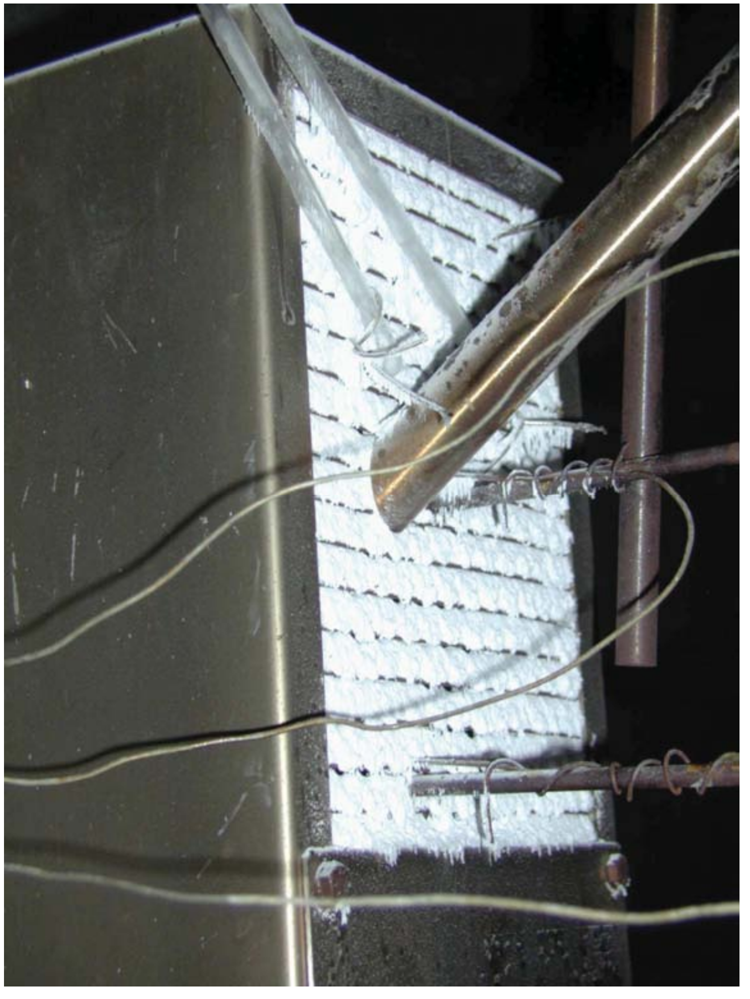
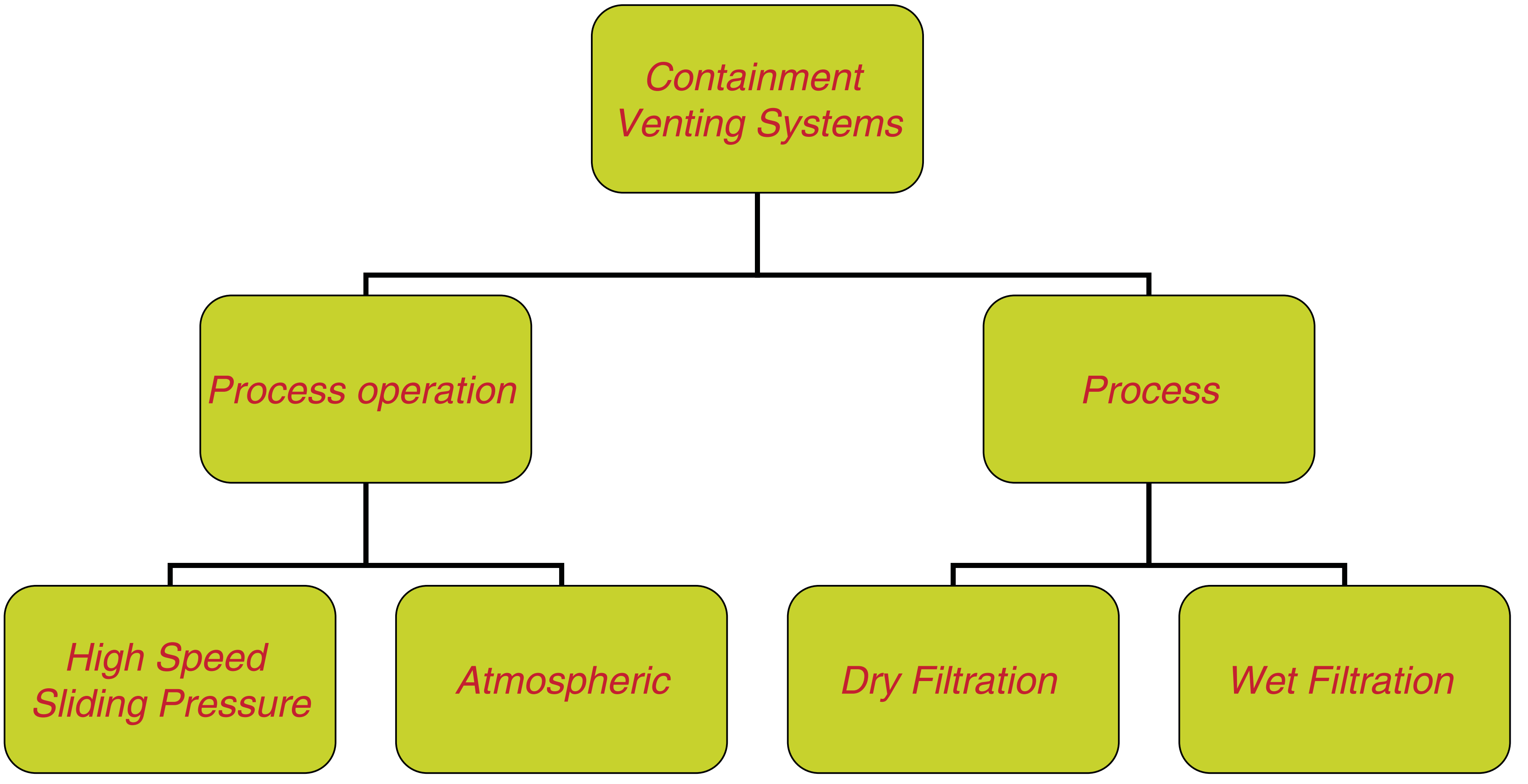
High Aerosol Concentration Phase
In-containment OECD
OECD PAR Testing, outlet fine grid version



- ►Impression of clogging behavior of hygroscopic aerosols
- ►Grid clogging with CsI

Overview of Venting Systems
Systematic Classification



FILTRA

BARSEBECK

A VERSATILE CONTAINMENT
FILTERED VENTING SYSTEM

…the very first design ..

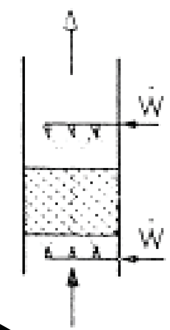
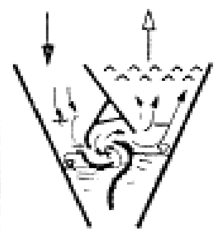
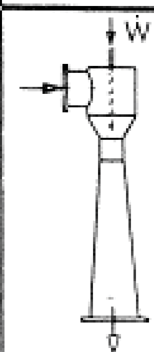
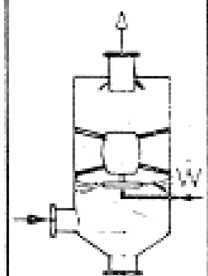
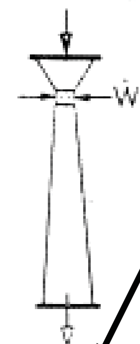
Gravel Bed Barsebeck

SYDKRAFT

Retention Efficiencies of Scrubber Solutions

Static Mixers (packings ets.) only retain large size aerosols

(because the relative low velocities)

Type	Washing Column	Cyclon dust catcher	Jet Scrubber	Rotary Sprayer	Venturi
Aufbau					
50% retained particle	> 1,1 μ	0,7 – 1,0 μ	0,6 – 0,9 μ	0,4 – 0,6 μ	< 0,1 – 0,4 μ
Rel. speed m/s	1	8 – 15	15 – 25	25 – 50	40 – 150
Pressure drop 10 Pa	20-200	180 – 280	—	40 - 100	300 - 2000
Water / Air liter / m3	0,05 - 10	?	5 - 25	0,8 - 3,5	0,5 - 5
Energy input kWh/1000m3	N_L = 0,1 – 1,2 N_W = 0,01 – 5	N_L = 1 – 1,2 N_W = 0	N_L = 0 N_W = 6,5	N_L = 0,2 – 0,5 N_W = 2 – 4	N_L = 1,5 – 7 N_W = 0,1 – 1,5

Lit: Dr. Muschelknautz,

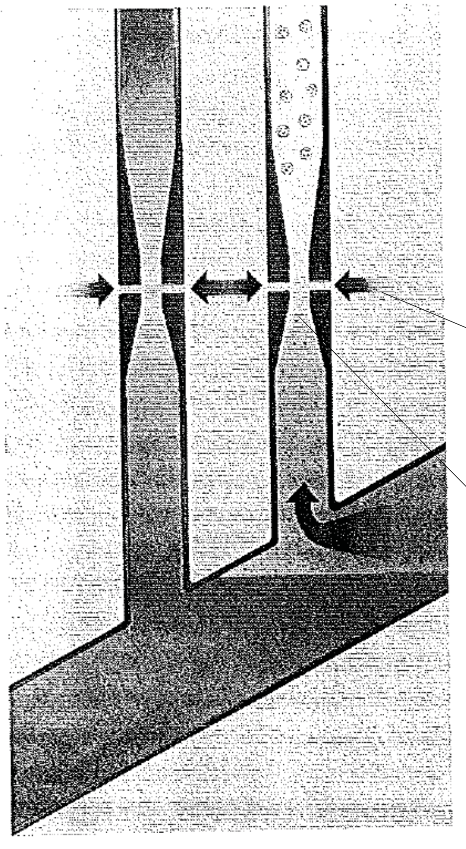
Mehrphasenströmungstechnik

Venturi scrubbers are capable of small particle retention

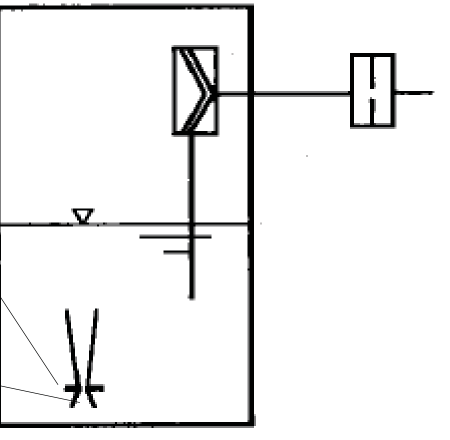
High gas speeds must be attained for small particle retention.

Remaining issue: Method of venturi speed control

Venturi Principle



FILTRA-MVSS
Basic principle



Sliding Pressure

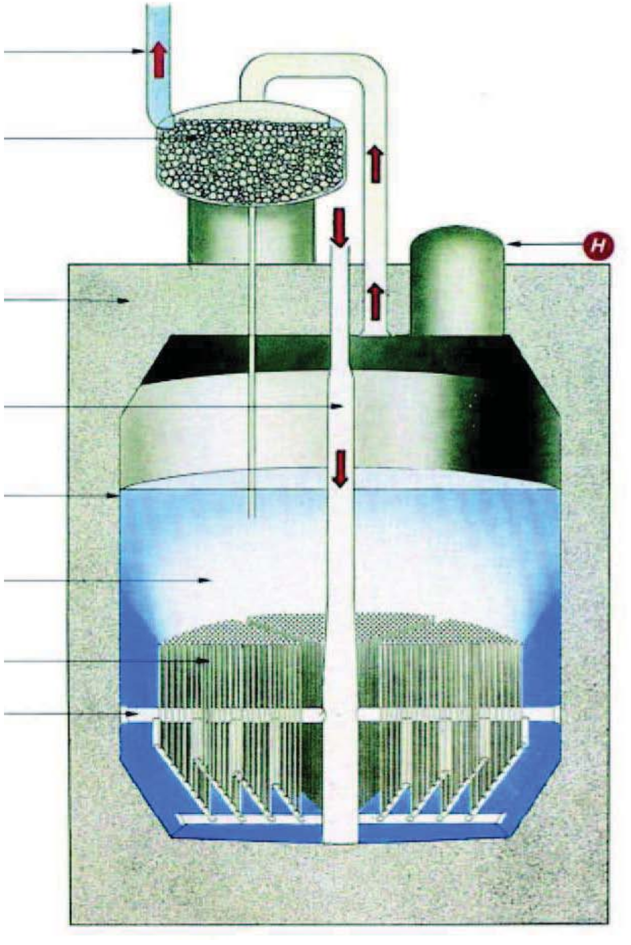
Venturi Scrubber Unit

Overview of Venting Systems
Scrubber Systems – Atmospheric Pressure

Building of Atmospheric Venting Unit (ABB) in Oskarsham NPP (Sweden)

Overview of Venting Systems
Comparison of Scrubber Dimensions

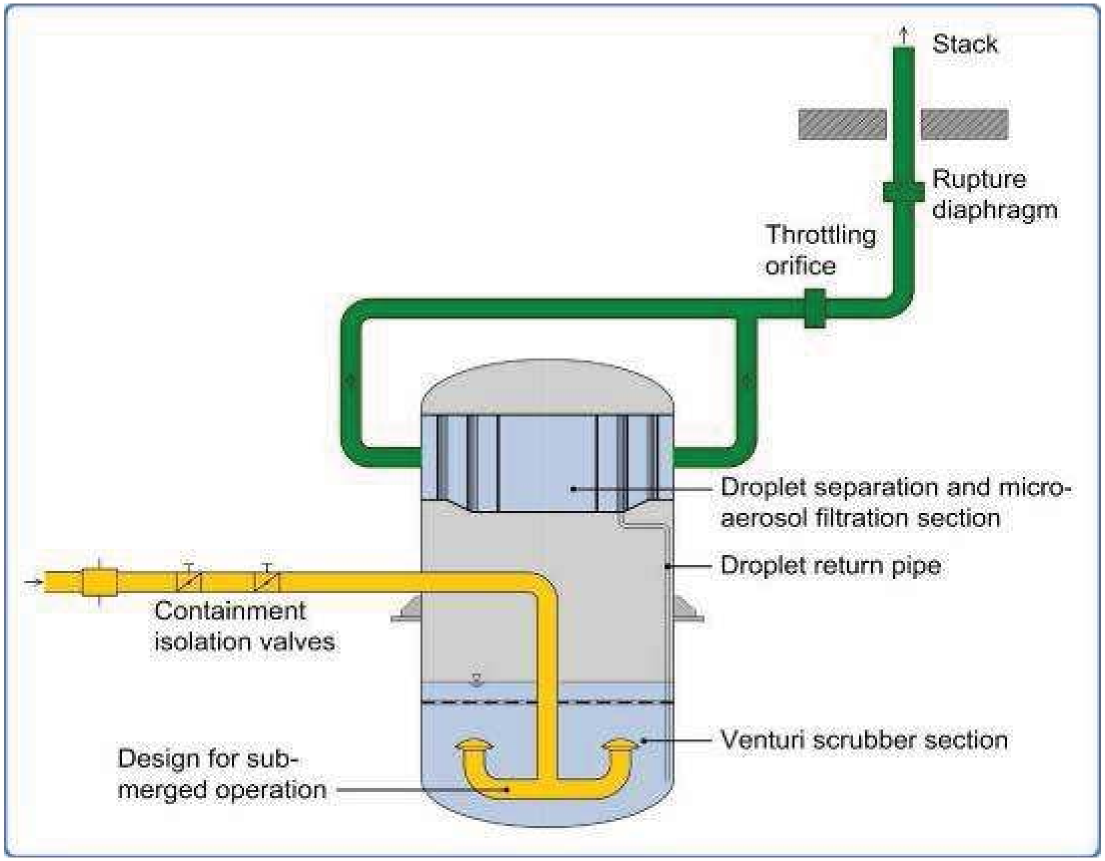
- **Scrubber Systems**
  - Atmospheric Pressure (ABB)



Process design based on metallic & ceramic substances only

Installation:
- all Swedish units
- Mühleberg, Swiss:

AREVA´s Standard
High Speed Sliding Pressure Venting [1)]

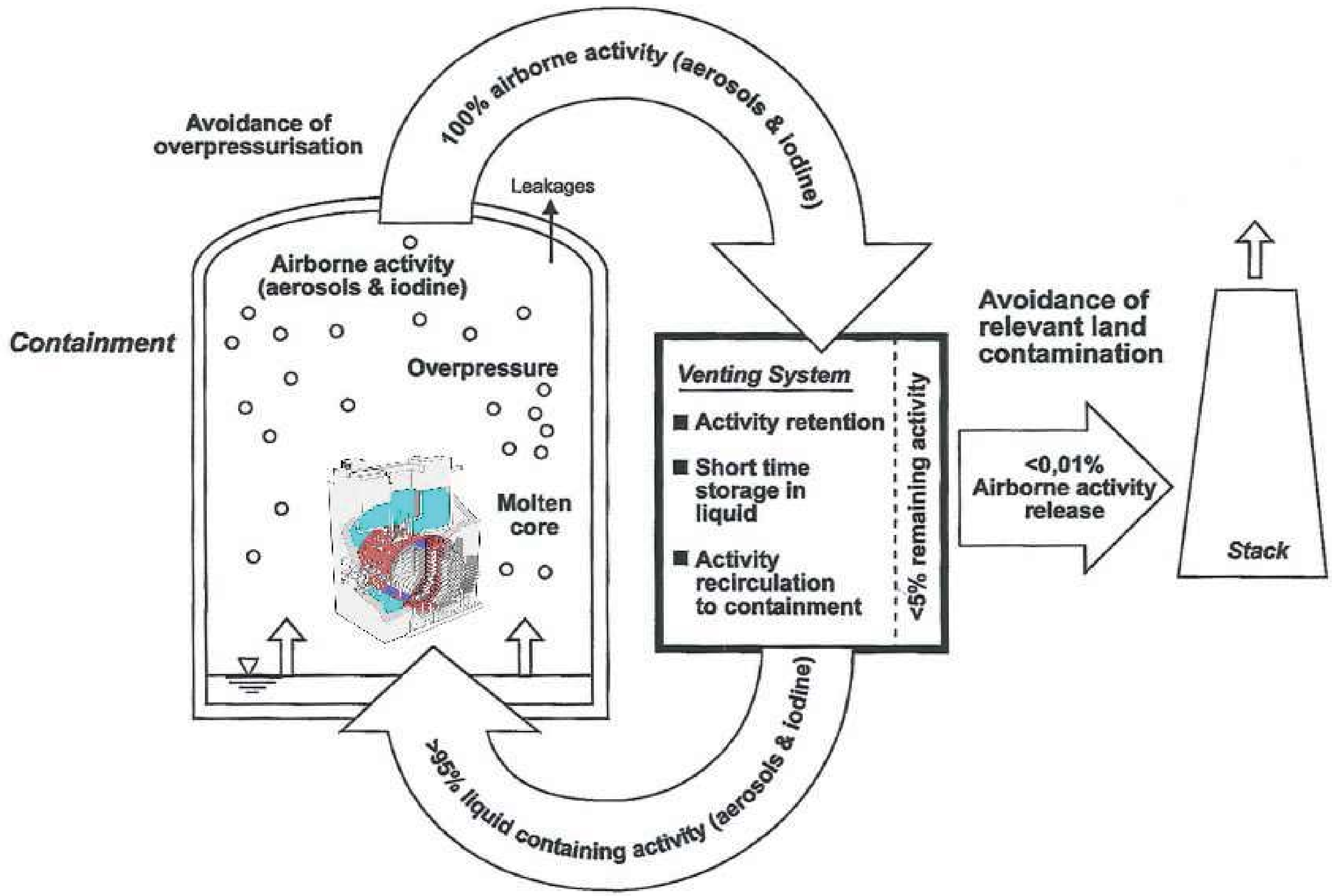


Applications:
- ➢**50, see ref list**
- ➢**(Siemens-KWU -- AREVA)**

- **1st Filtration Stage:** **High Speed Venturi Scrubber Section**
- **2nd Filtration Stage:** **Metal Fibre Filter Section**
- **Passive speed & sliding pressure control**

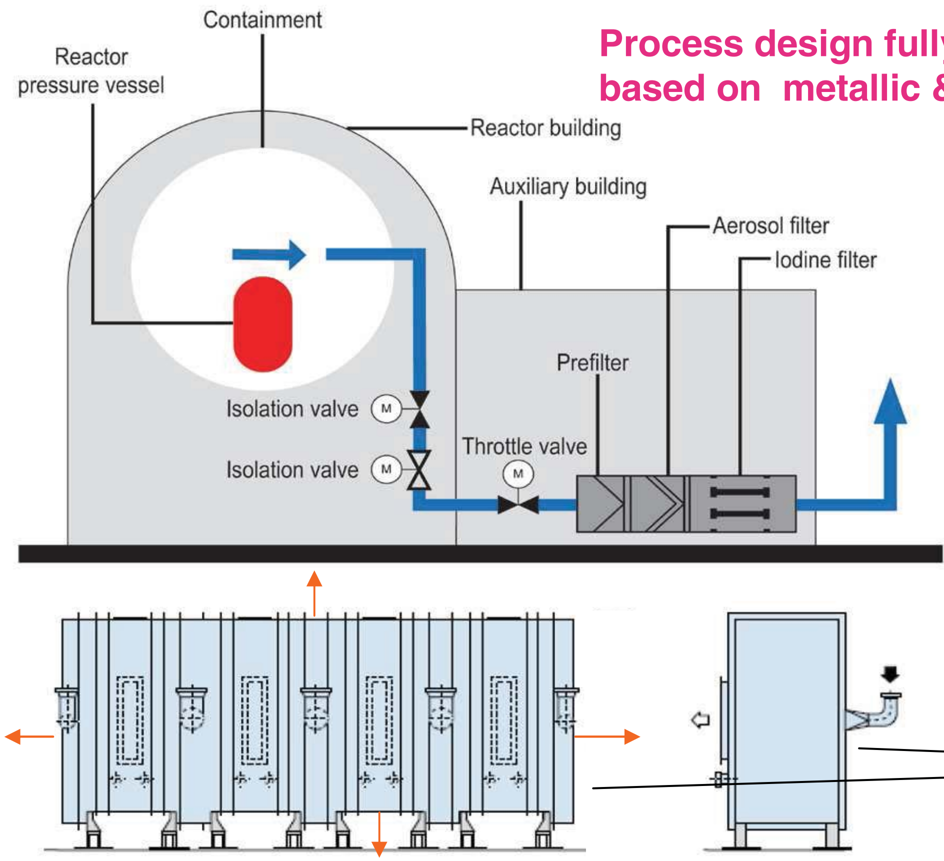
1) Patent rights reserved

Venting Overview Scrubber feature: Mid term activity transfer back into containment



Overview of Venting Systems
Dry Filter Systems – Atmospheric Pressure

Process design fully
based on metallic & ceramic substances only

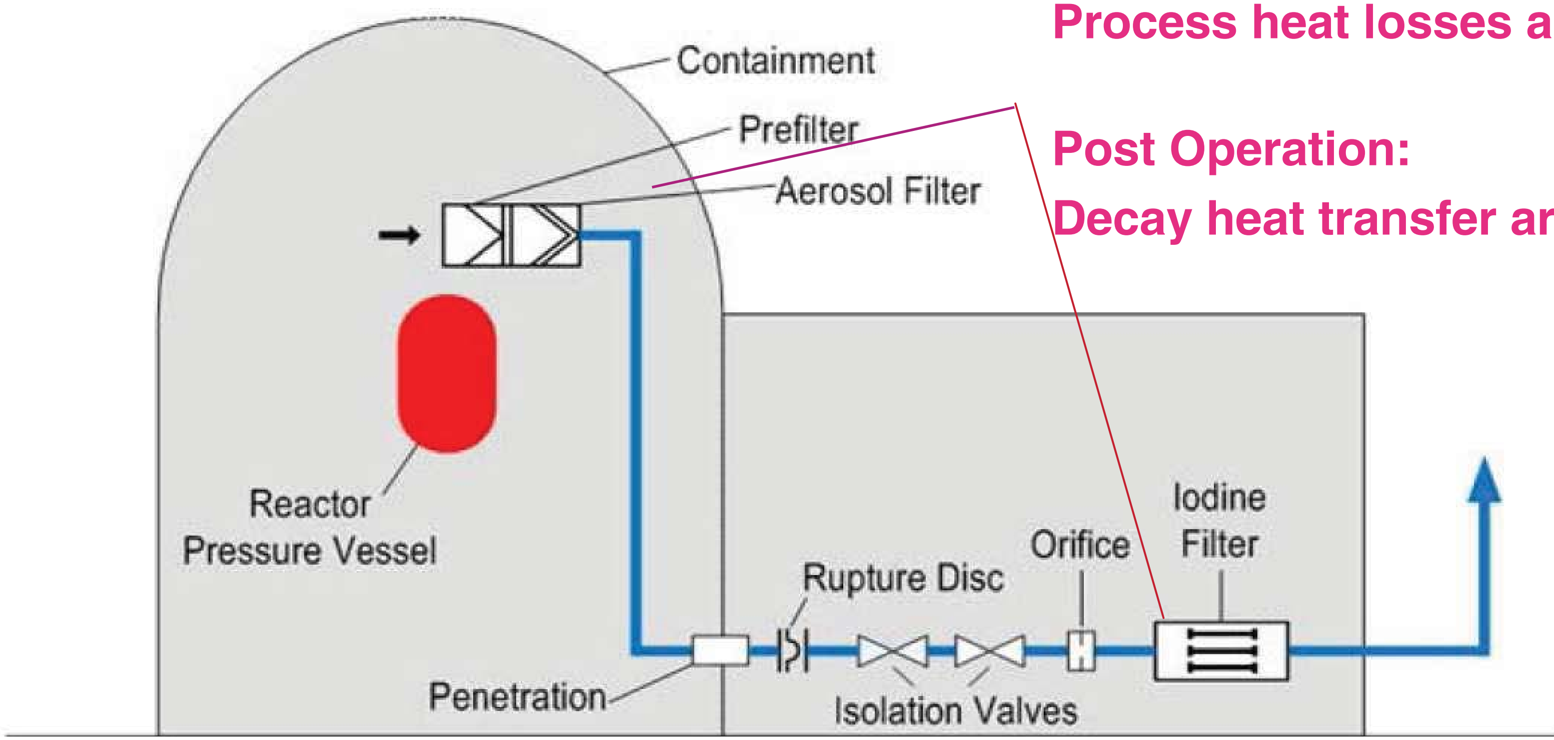


Operation:
Process heat losses area

Post Operation:
Decay heat transfer area

Dry Filter System (FZK / YIT / ......)

Overview of Venting Systems
In-Containment Dry Filter Systems
Sliding Pressure Version



Operation:
Process heat losses area

Post Operation:
Decay heat transfer area

(RWE / FZK-YIT / .....)

Other Solutions

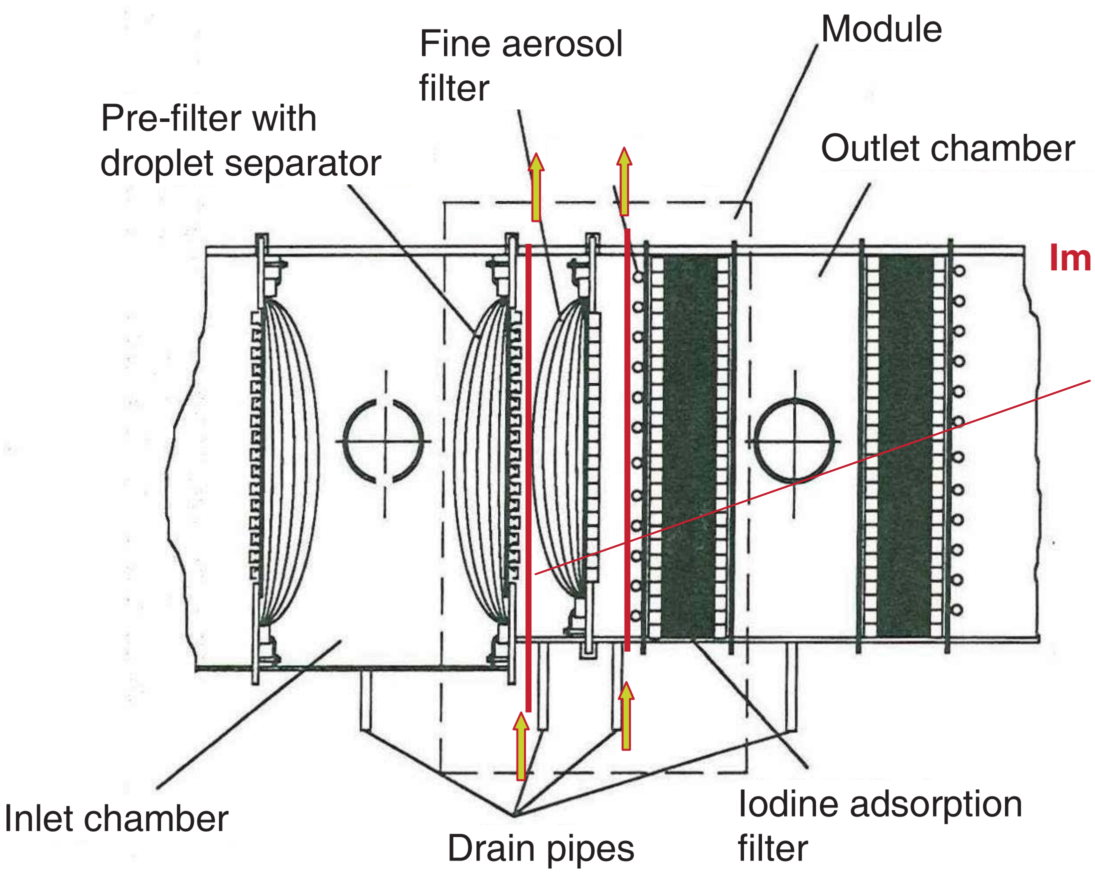
- **Siemens/AREVA in-Containment Solutions (metal cartridges and scrubber)**

  - **Basic testing performed and discussions hold with authorities**

  - **Finally cancelled**

Metal Fiber Filter Sketch

Decay heat transfer after operation
Issue: Very low heat conductivity of fiber layers



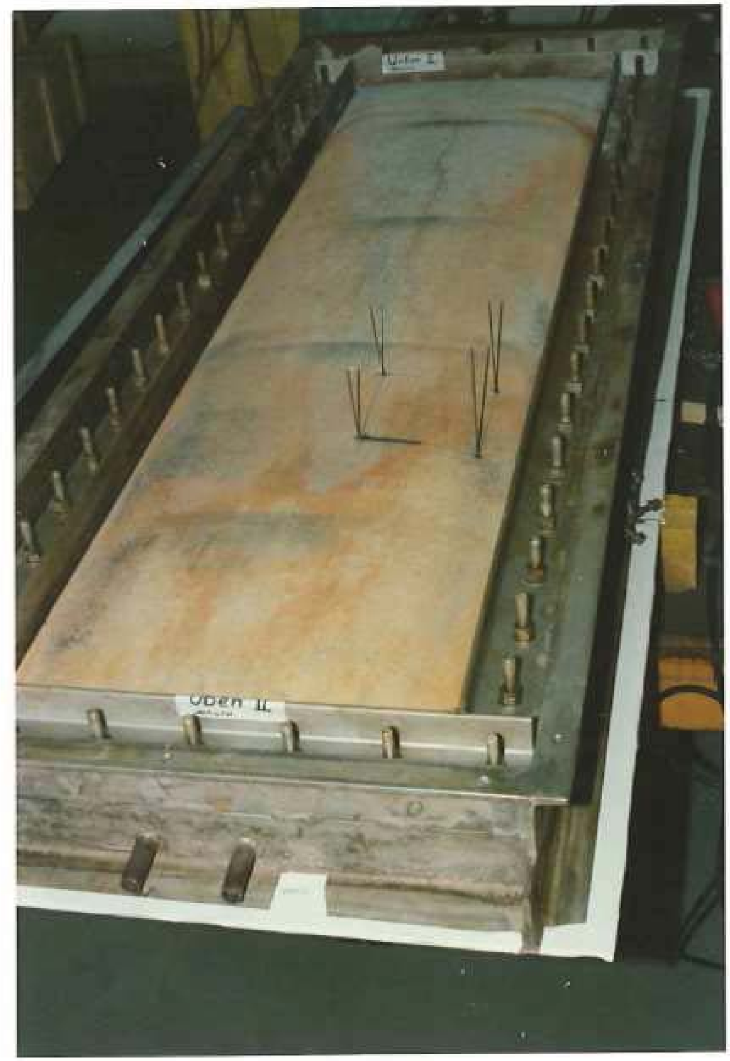
Improvement of metal fiber layer decay heat transfer

Discussed option cooling tubes:

-out-fiber layer cooling: inefficient

- In-fiber layer cooling:
potential, issue filter bypass to be solved

JAVA – Test Process Optimisation of MFF design and operation



Very low heat conductivity of metal fibers (similar to thermal insulation)

- ►Very small decay heat transfer by heat conductivity possible (limiting part)
- ►Decay heat transfer/removal by forced flow trough the fibers is efficient

Issue : Decay heat removal from dry filter modules

▶ The Temperature Behavior

IX. The Temperature Behavior

The materials used in venting filters resist temperatures of up to 400 to 500 °C. During filter operation the filters are cooled by the air-steam mixture; when disconnected, the filters should release the decay heat of the fission products without requiring active cooling measures, i.e. solely through convection and heat radiation. Since the relevant computations are very complex, true-scale filter modules with electric heaters integrated in the layers of the metal fiber filters and in the molecular sieve layers were heated. At constant temperatures of approx. 400 °C in the layers establishment of the temperature equilibrium was awaited and the electric power feed was measured (Fig. 10 and 11). It appears that the decay heat to be expected can be removed in a passive mode without cooling.

CsOH melting point

In-containment temperature range

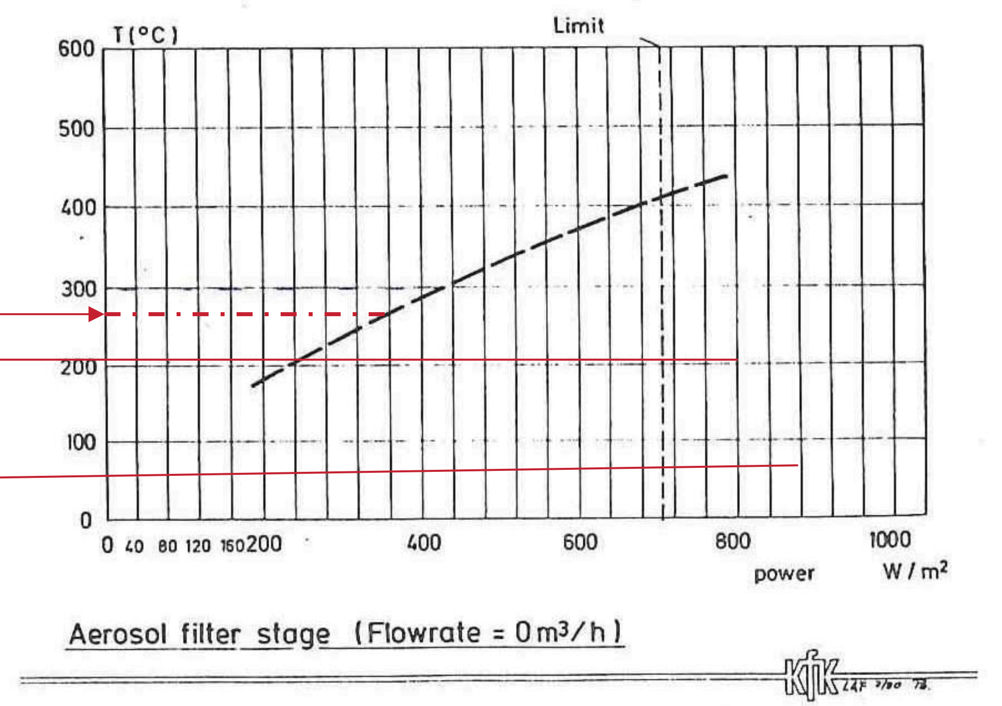


Fig. 10 Temperature as a function of decayheat

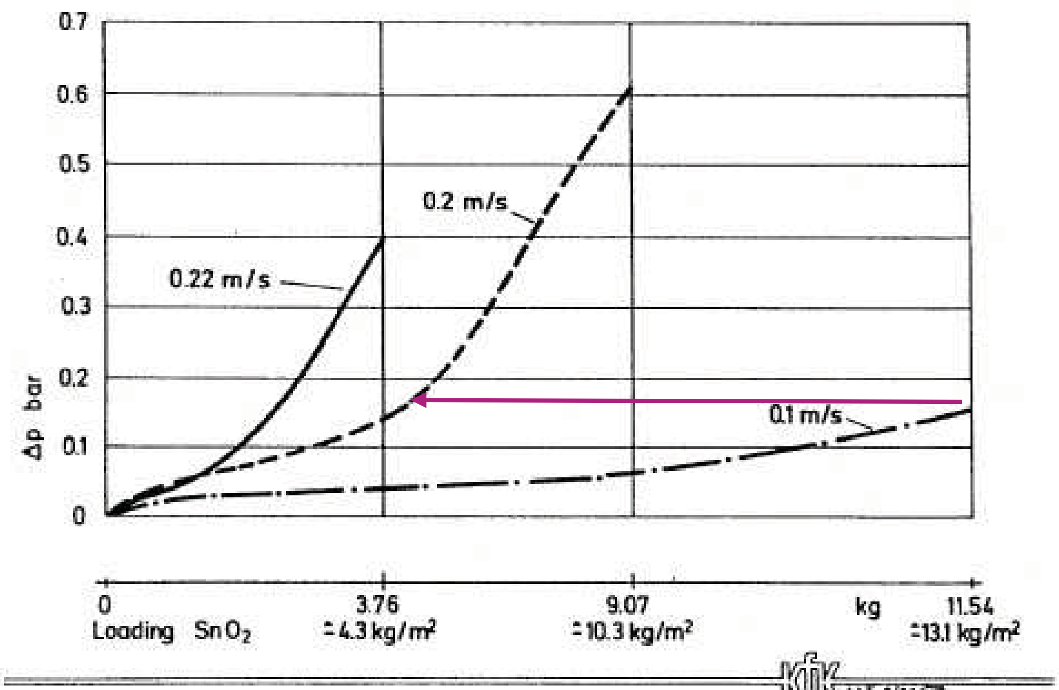
AREVA conclusion:

Dry filters max. decay heat values of e.g.

- **out-containment solution < 400 W/m2 ,**
- **in-containment solution down to < 100 W/m2**

Aerosol Loading Test MFF

Sensitivity of loading capacity on filtering parameter, e.g. as velocities, pressure..



Loading tests with ventingfilter 0.88 m², different types
Aerosol: SnO_2, $d_{50\%}$ ~ 0.5 µm particlediameter

Deep bed filtration:

Changes of certain operation conditions, e.g. as in-containment high pressure/temp., velocity, gas density, dynamic viscosity, aerosol types, moisture, etc., result in specific fiber layer retention efficiencies and causing finally strongly different filter loading capacities.

Example: Increase of velocity to 0.2 m/s reduces loading capacity by factor 3.

Specific German Venting system Requirements RSK (1991)

III. Auslegung des Filtersystems für luftgetragene Stoffe

	DWR	SWR
Aerosolmasse	40 kg 4)	20 kg 4)
Nachzerfallsleistung:		
Aerosole	2 kW	180 kW
gasförmiges Jod	5 kW	7 kW
Mindestabscheidegrad:		
Aerosole	99,9 %	99,9 %
elementares Jod	90,0 %	90,0 %
organisches Jod	0,0 %	0,0 %

IV. Belastung des Filtersystems durch Spaltprodukte (Anteile des Kerninventars)

	DWR	SWR
elementares Jod	$1x10^{-3}$	$4x10^{-4}$
organisches Jod	$1x10^{-3}$	$2x10^{-4}$
CsJ, CsOH	$2x10^{-4}$	$3x10^{-2}$
Te	$3x10^{-3}$	

▶ **BWR:**
Because higher values
only application of scrubber technology

▶ **PWR :**
Very low values 1) for specific German PWR design enables dry filter application

1) Analysis for German PWR´s showed venting start (large, heavy containments) after 2 to 3 days of onset of S.A.
This late venting results in considerable low decay heat values of 7 kW

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Conclusion on dry filtering technology (DFM)
Metal fibre filter & molecular sieve

Consequences in Germany

- **BWR´s :**
  - **In general no DFM application at BWR´s** (see decay heat)

- **PWR`s**
  - **Out-containment DFM still in operation**
  - **Latest Convoy NPP´s** replaced out-containment dry filter systems by
    - **Venturi Scrubber systems**
      or
    - **added Venturi Scrubber units**
  - **In-containment dry filter systems (DFM) no more in operation after the FKS NPP (Biblis A&B) shout down**

Conclusion on dry filtering technology Metal fibre filter & molecular sieve

(without thermal insulation and recuperative heat transfer)

- **Molecular sieve iodine retention efficiency :**
  - very high molecular iodine retention
  - only partial superheating possible,

    because process design heat losses of filter elements (decay heat transfer) could not provide passive superheated conditions at molecular sieve stage

- **See RSK decision considering the real filter system features at this time:**
  - **No organic iodine retention required**

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Dry Filter Systems

Sand Bed Filter

Installation and Improvement Steps:

Step 1: Sand bed filter

Step 2: In - containment metal pre-filter

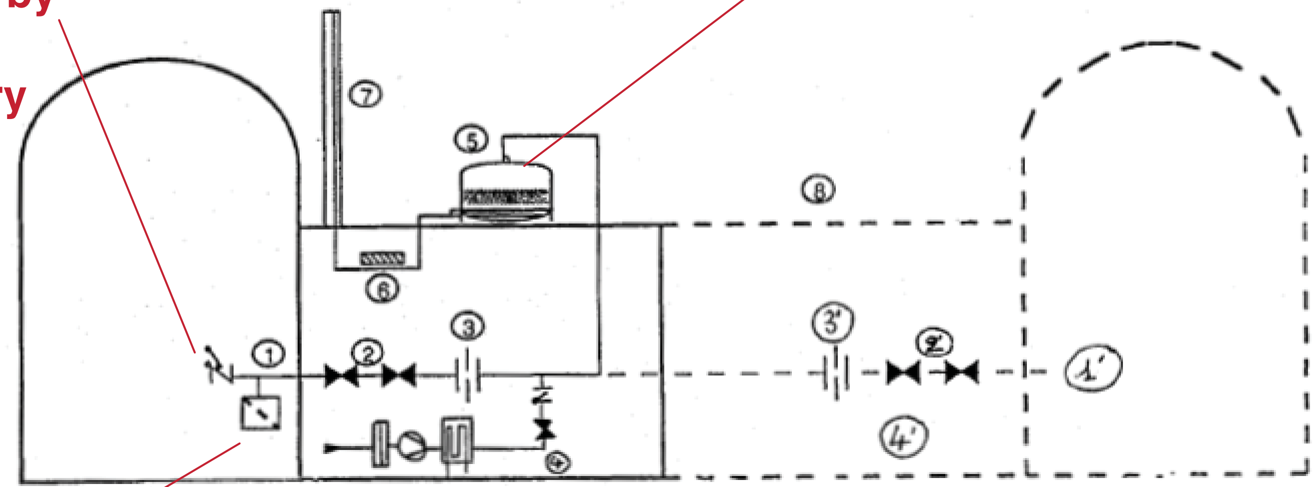
Step 3: In- containment by-pass

Step 4: …under discussion

Dry Filters

(Pre-Filter & Sand Bed Filter Combination)

Containment Pre-filter by-pass necessary



Containment Pre-filter (metal cartridge)

LEGEND:

1. Pre-filter;
Existing penetration, 300 mm diameter for 1300MWe plants, 250 mm diameter for 900 MWe plants.

2. Manual valves, operatd by reach rods from behind shelding.

3. Pressure letdown orifice.

4. Filtered dry air supply during normal operation / Preheating for "H2 risk" in case of SA

5. Sand filter.

6. Radiation monitor

7. Plant stack, with small vent stack

8. Arrangement for twin units (900 MWe)

Installed at all French units

Schematic diagram of the containment venting system

Design principle:

- **Process design based on metallic & ceramic substances only (no Hydro carbons)**
- **Containment internal filter by-pass to ensure reliable venting function**

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Dry Filters Technologies

PAUL SCHERRER INSTITUT

ORGANISATION FOR ECONOMIC

CO-OPERATION AND DEVELOPMENT NUCLEAR ENERGY AGENCY

STEERING COMMITTEE FOR NUCLEAR ENERGY

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

WORKSHOP ON THE IMPLEMENTATION OF

SEVERE ACCIDENT MANAGEMENT MEASURES

Paul Scherrer Institut, Villigen-PSI, Switzerland

10-13 September 2001

Organised in collaboration with

Kernkraftwerk Beznau (KKB)

Kernkraftwerk Leibstadt (KKL)

Electricité de France (EDF)

and

Paul Scherrer Institut (PSI)

Pre-print of the Proceeding of the Worksop containing preliminary versions of the papers

31.08.2001

Paul Scherrer Institut • 5232 Villigen PSI

- main characteristics of the reference fluid to be filtered :
  - # pressure at the entrance of the system : containment design pressure (5 bar abs) or "ultimate" resistance pressure (depending from the type of plant),
  - # temperature : 140 °C (at containment design pressure),
  - # flow rate : 5 kg/s (at containment design pressure),
  - # density : 4 kg/m^3 (at containment design pressure),
- minimum filtration efficiency : 10 (related to aerosols).

3.4 Sand bed filter

This filter, patented by EDF, is made of stainless steel. It is a vertical axis cylinder with torispherical upper and lower ends. Its main dimensional characteristics are the following :

- diameter : 7,3 m,
- height : 4 m,
- empty weight : 12 metric tons,
- operational weight : 92 metric tons (sand : 65 metric tons).

The sand bed is supported by layers of light weight concrete and expanded clay.

The gas mixture is collected by a network of stainless steel strainers located in the expanded clay and is exhausted to the filter periphery via a rectangular section torus.

In air plus steam gas mixture the behaviour of metallic filtration media is totally different in presence of highly hygroscopic aerosols (CsOH during tests) or non hygroscopic aerosols :

- hygroscopic aerosols : very slight pressure drop at the beginning followed by a very strong increase and sudden pressure drop leading to flow rate blockage,
- non hygroscopic aerosols : regular increase of pressure drop proportional to aerosols mass trapped.

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EDF/IRSN Tests on loading capacities: Soluble and insoluble aerosols

DESIGN OF A PREFILTER TO IMPROVE
RADIATION PROTECTION AND FILTERING EFFICIENCY OF
THE CONTAINMENT VENTING SYSTEM

by Maurice V. Kaercher,
Electricite de France
Lyon, France

Abstract

The sand bed filters installed on all French PWR reactors are designed to retain the source term of radioactivity, inside the containment, 24 hours after the beginning of core melting. Because of its large dimensions, the sand filter is located outside the containment : after operation, the source term which may be inside the sand filter provides a very high radiation level on the site.
To cope with this difficulty, studies were led in two directions :
. biological shieldings,
. design of a complementary filter (prefilter) located inside the containment and able to keep 90 per cent of the radioactivity inside .
This paper describes the main results of the R&D programs implemented in 1991 and 1992 to develop the prefilter. It covers the following items :

- main assumptions on quantities and sizes of aerosols in two main accident scenarios (core melting and core concrete interaction),
- basic design requirements for the prefilter,
- description of laboratory tests performed in various conditions of temperature and pressure with :
  . hydroscopic aerosols (CsOH),
  . nonhydroscopic aerosols (TiO_2, SiO_2, SZn),
  . a mixture of both,
- main results on filtering efficiency, pressure drop, capacity of retention and choice of accurate metallic media,
- main conclusions, program of installation on French PWR Units.

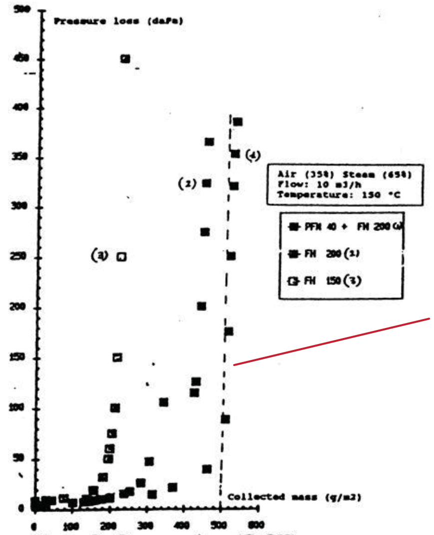

Figure 8 : Pressure drop (CsOH)

Sudden Filter Clogging phenomena at 0,5 kg/m2, hygroscopic aerosols

6.2. Filtration tests with insoluble aerosols

These tests were performed in PALL Laboratories in Porsmouth (GB) with SiO_2 and TiO_2 aerosols. The main results are given in figure 9.

We observed :

- a increasing drop in pressure with a slope between 2 and 5 g/m^2 mbar,
- a positive contribution due to the fall of aerosol coating,
- the filtering efficiency is higher than 90 per cent.

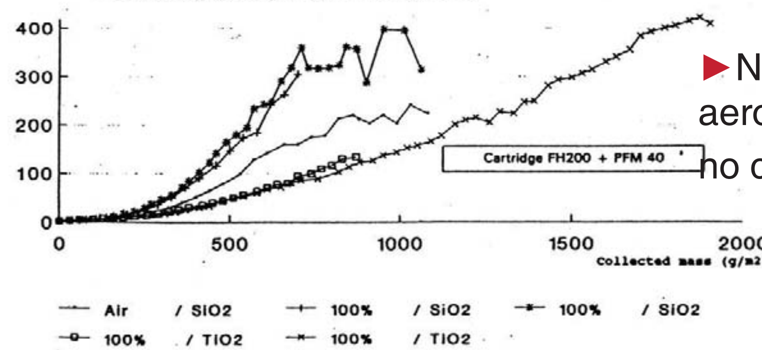

Figure 9 : Pressure drop (FH200 + PFM40)

►Non hygroscopic aerosols > 2 kg/m2- no clogging

Dry Filtration Methods
Aerosol Retention Metal Filters

- **Aerosol retention efficiency:**
  - **Very high retention efficiency of large and fine aerosols**
  - **Loading capacity**
    - medium to low for in general unknown aerosol mixtures and operating conditions , e. g. hygroscopic & non hygroscopic , wet - dry, densities…
      (see **EDF/IRSN/AREVA results:** e.g. down to < 0,5 kg/m2 **)**
    - Issues: Increased probability of formation of clogging layers/clogging membranes under higher aerosol loads,

      -e.g. reaching once 273°C CsOH,… aerosol melting c aused by decay heat releases or changing operating conditions, as saturation, pressure/temp. variation, velocities..
    - In–containment dry filter testing /qualification – under sliding pressure conditions (like JAVA) – to be verified by additional tests

Reliable venting function requires reliable exclusion of filter clogging phenomena's, therefore only low filter aerosol loads could be recommended.

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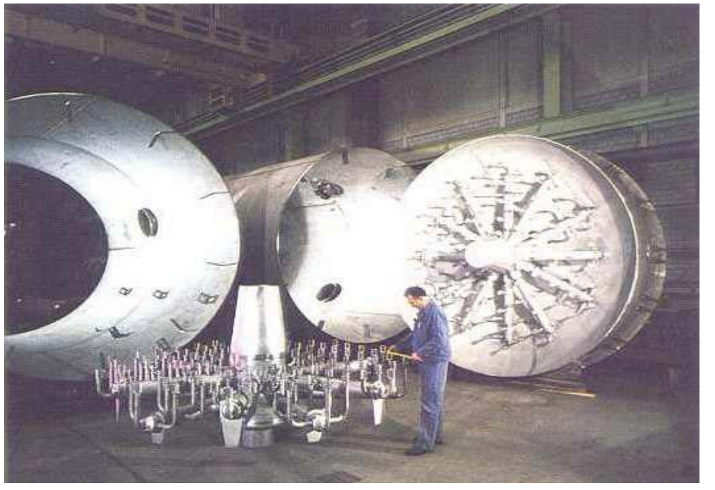
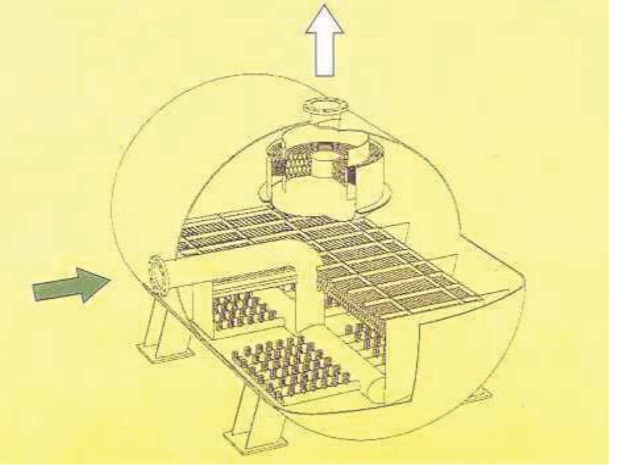
Scrubber Systems

Later/Further Scrubber Developments

Overview of Venting Systems
Scrubber Systems





Scrubber System (Sulzer/ CCI / IMI/..)

Installation:
-Bezneu 1&2
-Leibstadt

Standard Scrubbers Solutions and new Recommendations

- **Venting Scrubber uses the following standard chemicals for elemental iodine retention**
  - **NaOH**
  - **Na2S2O3**

New:

PSI recommends Aliquat injection into scrubber pools for organic iodine retention – Generation 2 FCVS?

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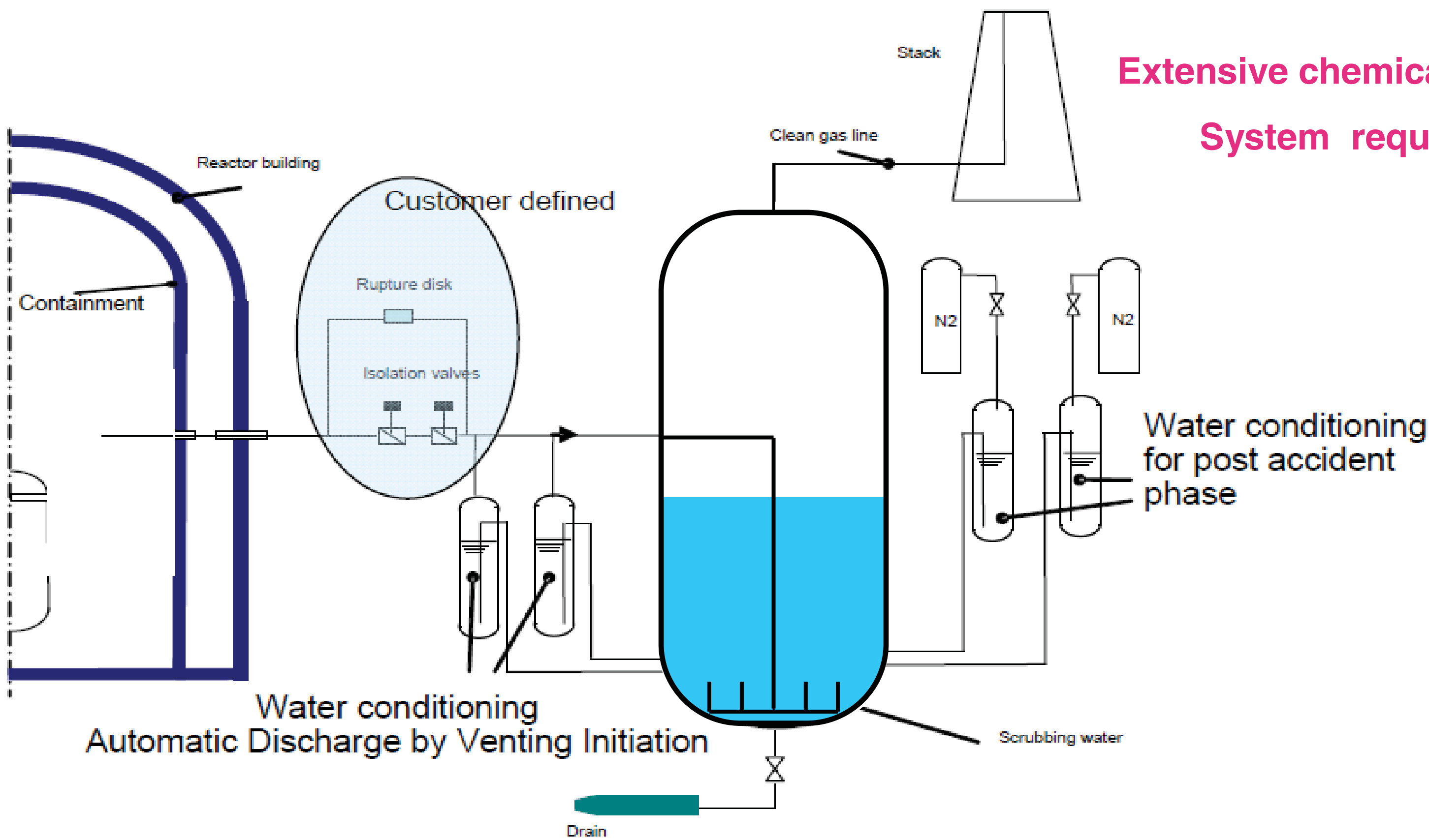
Challenges of Aliquat [1)] Injection into Vent Pools

[1)] **also promoted as phase transfer catalyst and co-agent**

New Proposals with Aliquat Injection and Foaming Control

Typical Implementation: Schematics



Extensive chemical control

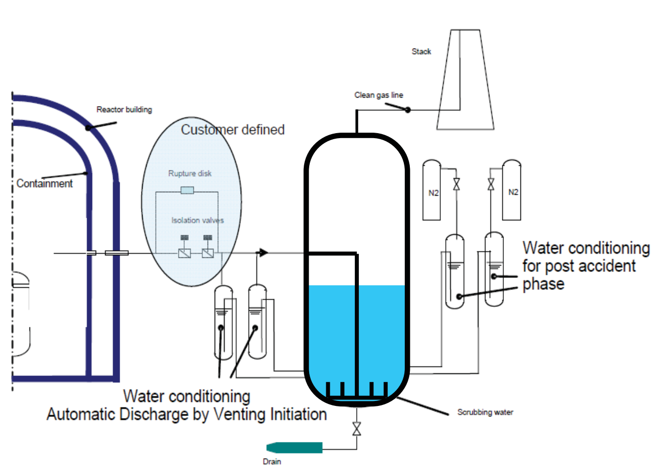
System required

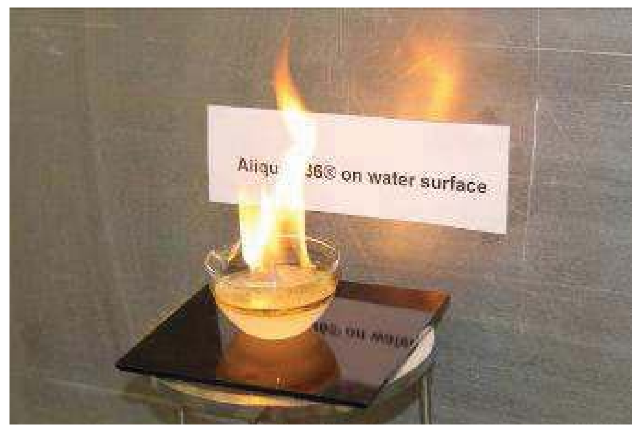
Conclusion of AREVA Investigations on Aliquat Injection into Scrubbers

- Aliquat injection requires <u>permanent</u> Anti-Foaming Control
- Pool, filter & outlet - combustion risk
- New source for formation of other additional organic iodine species
- Research on Aliquat for Iodine retention in the nuclear community just started

Based on the current knowledge

Typical Implementation: Schematics





» **AREVA chemical and safety experts recommends not to use any Aliquat injection into venting scrubbers**

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Process Selection

AREVA´s Process Selection

- **Disadvantages of Scrubber Solution**
  - Limited fine aerosol retention without high speed venturi contol
  - Droplet separation necessary
  - Resuspension effects

- **Disadvantages of Dry Filtration Systems**
  - High potential of filter clogging, especially if conditions change
  - Critical mixed aerosol behaviour
  - Decay heat transfer must be solved safely

» **AREVA Selection of Combined Process to eliminate the disadvantages**

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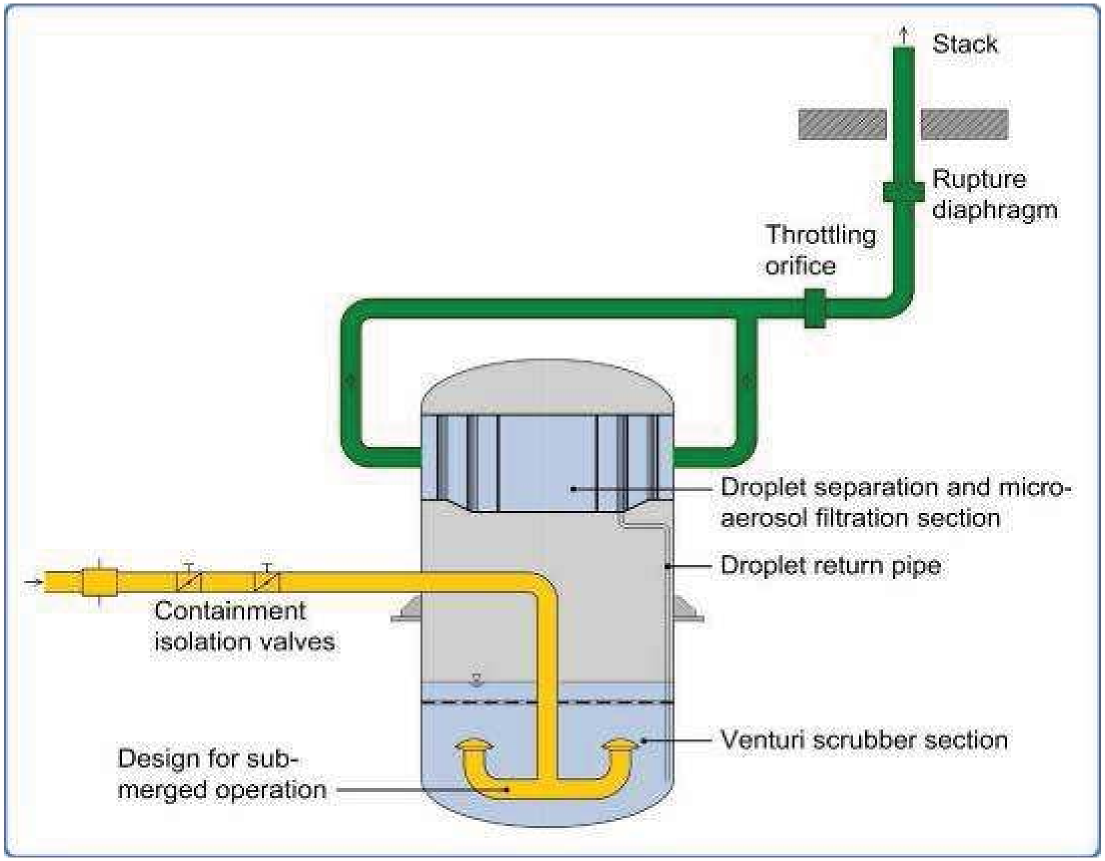
AREVA Process

AREVA´s Standard
High Speed Sliding Pressure Venting 1)



- **1st Filtration Stage:** **High Speed Venturi Scrubber Section**
- **2nd Filtration Stage:** **Metal Fibre Filter Section**
- **Passive speed & sliding pressure control**

1) Patent rights reserved

Key Technology
Specific Features

Sliding pressure operation

- Passive venturi high speed control by speed of sound (mach 1) throttle velocity results in mach 1 e. g. for saturated steam app. 450 m/s) -

  - optimized process velocities (high speed to very high speed)

  and

  - super heated condition down stream throttling

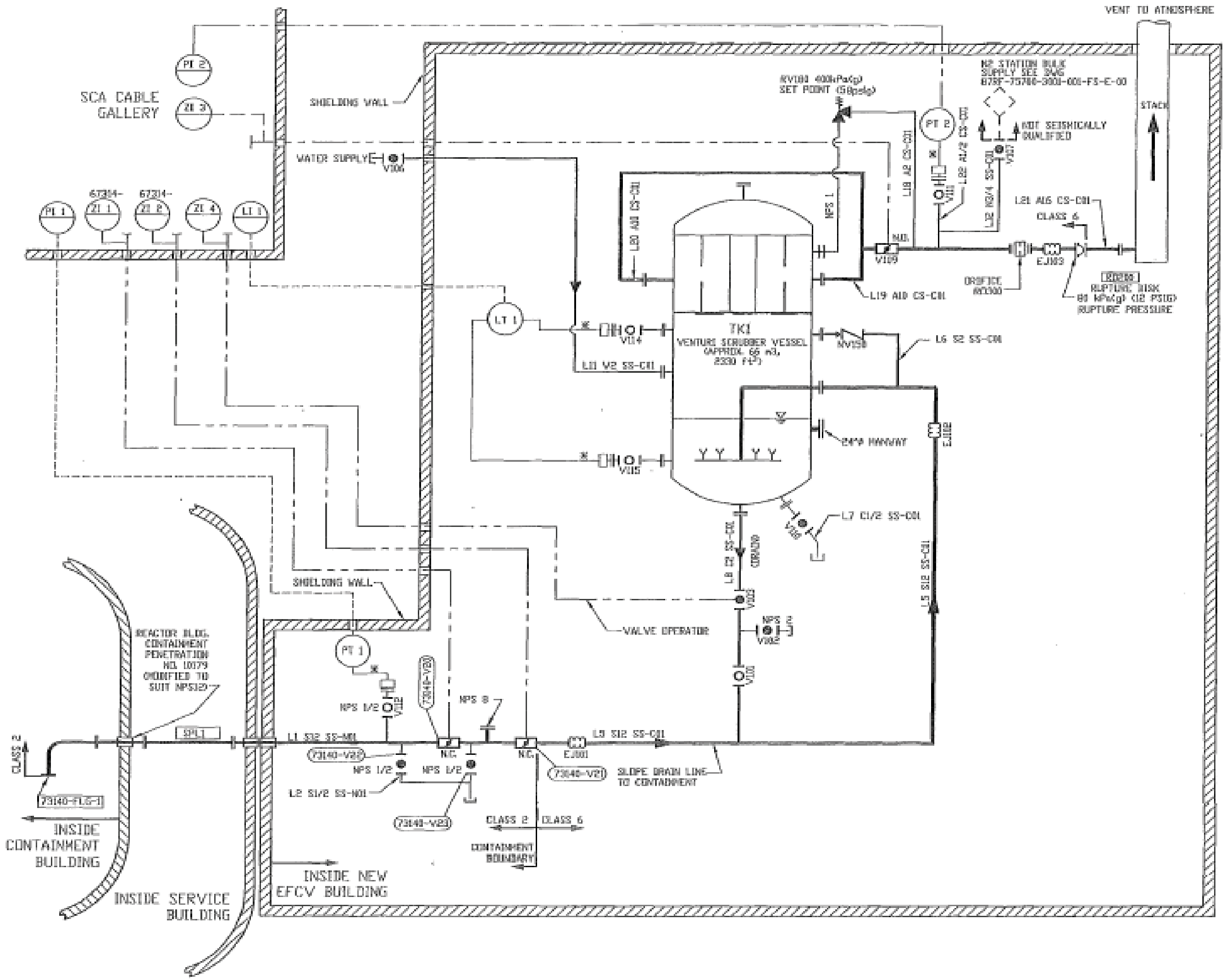
- Only high speed causes very efficient scrubber retention and
  - avoids overload of second fine aerosol filter stage
  - guaranties reliable long term operation

- **Process Compactness, because gas treatment under pressure**

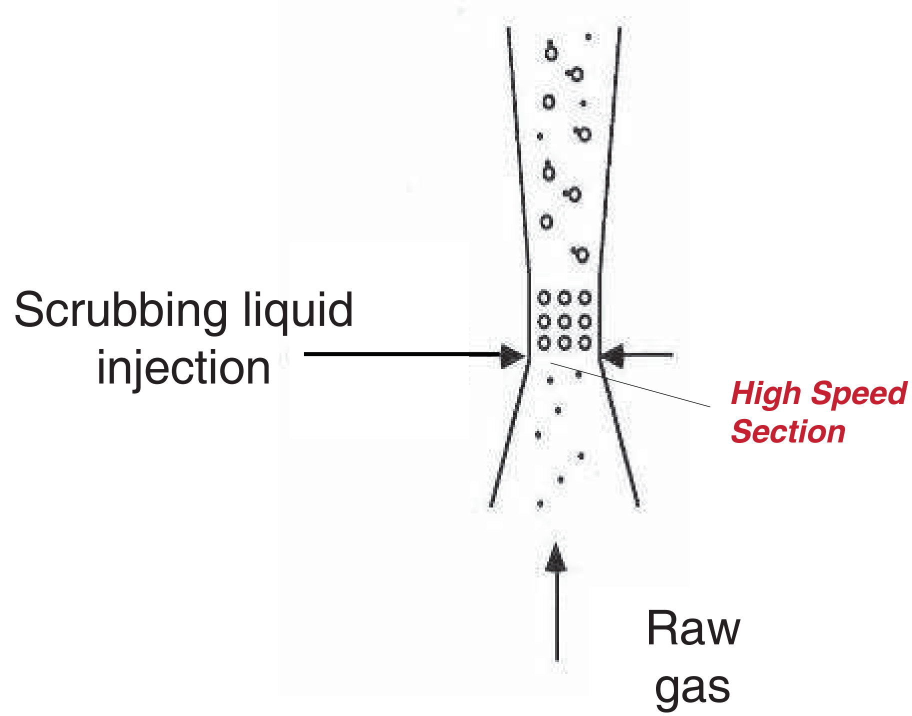
- Most efficient retention of large and fine aerosol fractions incl. penetrating fine aerosol fractions

  (see simulation tests ACE DOP and JAVA Uranine)

Process Flow Diagram
(CANDU6 Standard Design)



First Filtration Stage
Venturi Nozzle



High stability design for seismic resistance

Second Filtration Stage
Metal Fibre Filter

Metal Fibre Filter Combi:

- **Demister - Prefilter - Finefilter & Impingment separator**

<u>Performance</u>

+ Eliminates filter gap of the scrubber completely

+ Low gas speed (low pressure) does not affect filtration efficiency

+ Resuspended fine droplets are captured

High stability design for seismic resistance

High Speed Sliding Pressure Venting Decontamination Factors (DF)

DF for Aerosols:

- **Fine Aerosols** **> 10.000**
- **Large Aerosols** **> 100.000**

DF for Iodine

- **Aerosol Iodine** **> 1.000.000**
- **Elemental Iodine** **> 500**

New Developments to Improve Organic Iodine Retention

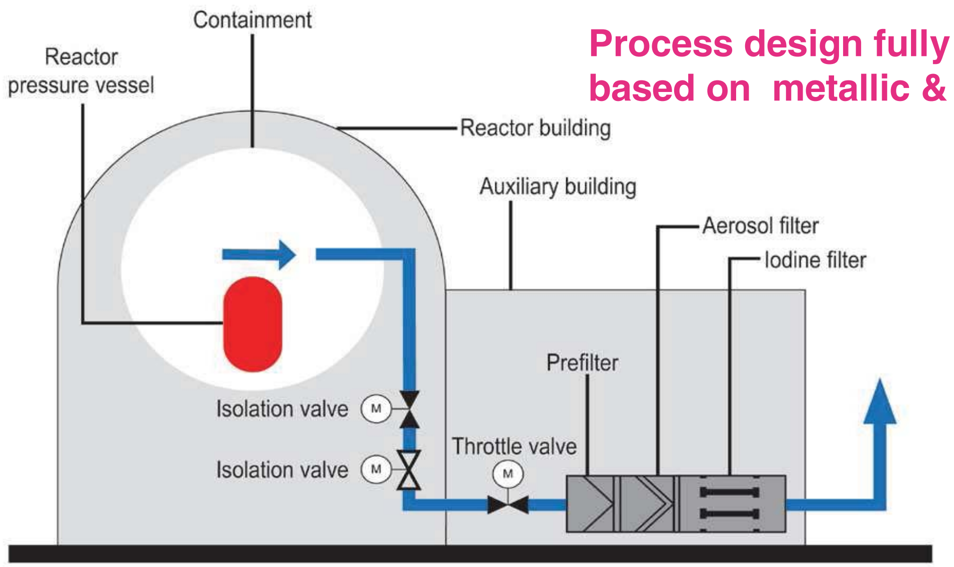
Situation:
Increased organic iodine retention of up to > 98% require in some countries.

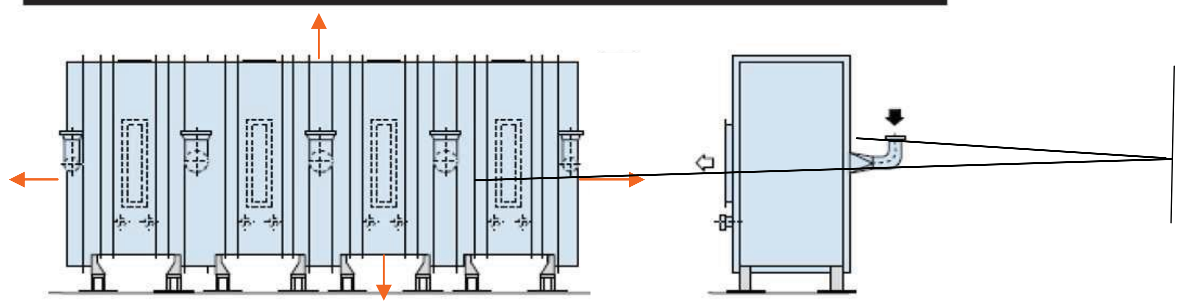
Principle Solution under discussion or qualification:

- **Aliquat injection (already addressed)**
- **DFM, incl. Molecular Sieve**
- **AREVA´s Standard**
  High Speed Sliding Pressure Venting Plus

Overview of Venting Systems
Dry Filter Systems – Atmospheric Pressure

Process design fully based on metallic & ceramic substances only





Operation: Process heat losses area

Post Operation:
Decay heat transfer area

Dry Filter System (FZK / YIT / ….)

AREVA´s Improved Organic Iodine Retention

- Sliding pressure operation creates passively
  - in combination with expansion drying very beneficial super heated gas condition
  - Specific process combination and design
    - recuperative heat transfer and efficient thermal insulation -
    avoids any relevant process heat losses at sorbents section

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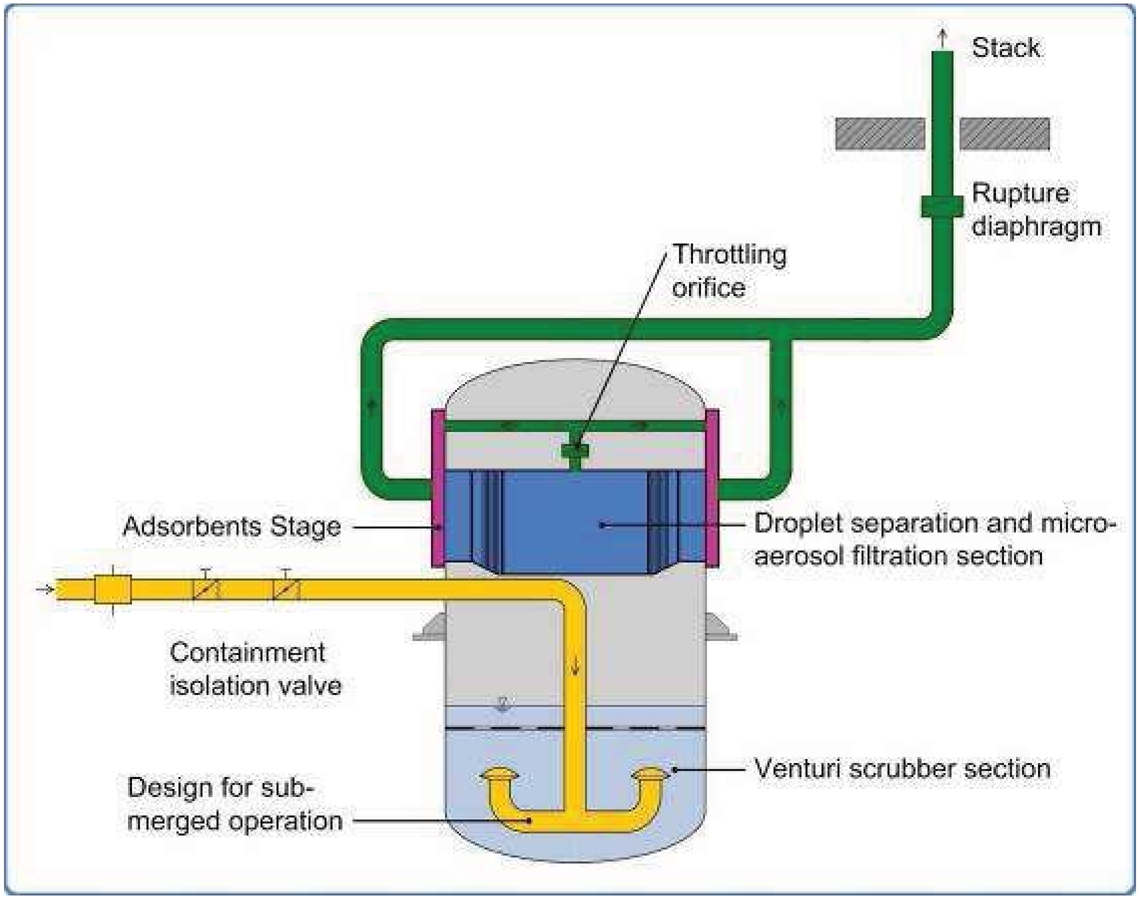
AREVA´s Standard High Speed Sliding Pressure Venting Plus



1. Venturi Scrubber

- Most aerosols retained
- Most iodine retained

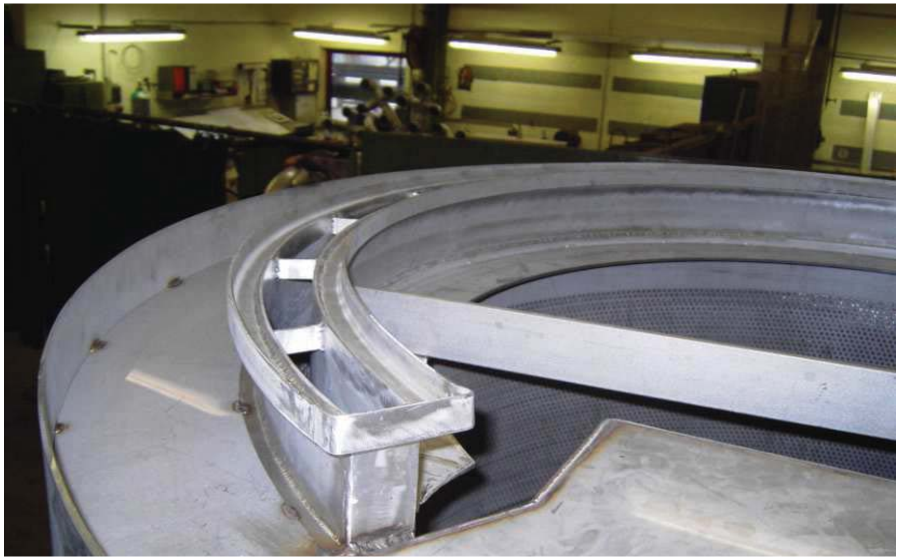
2. Metal Fibre Filter

- Large pre and fine filter surfaces
- Penetrated Fine Aerosols retained
- Re-suspension captured

3. Sorbents Section

- Retaining of remaining and re-volatilized iodine (Elemental & Organic)

Option:
Third Filtration Stage
Sorbents Section



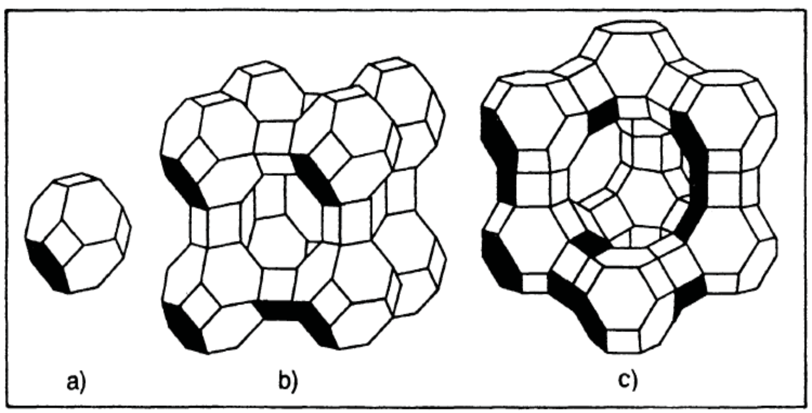
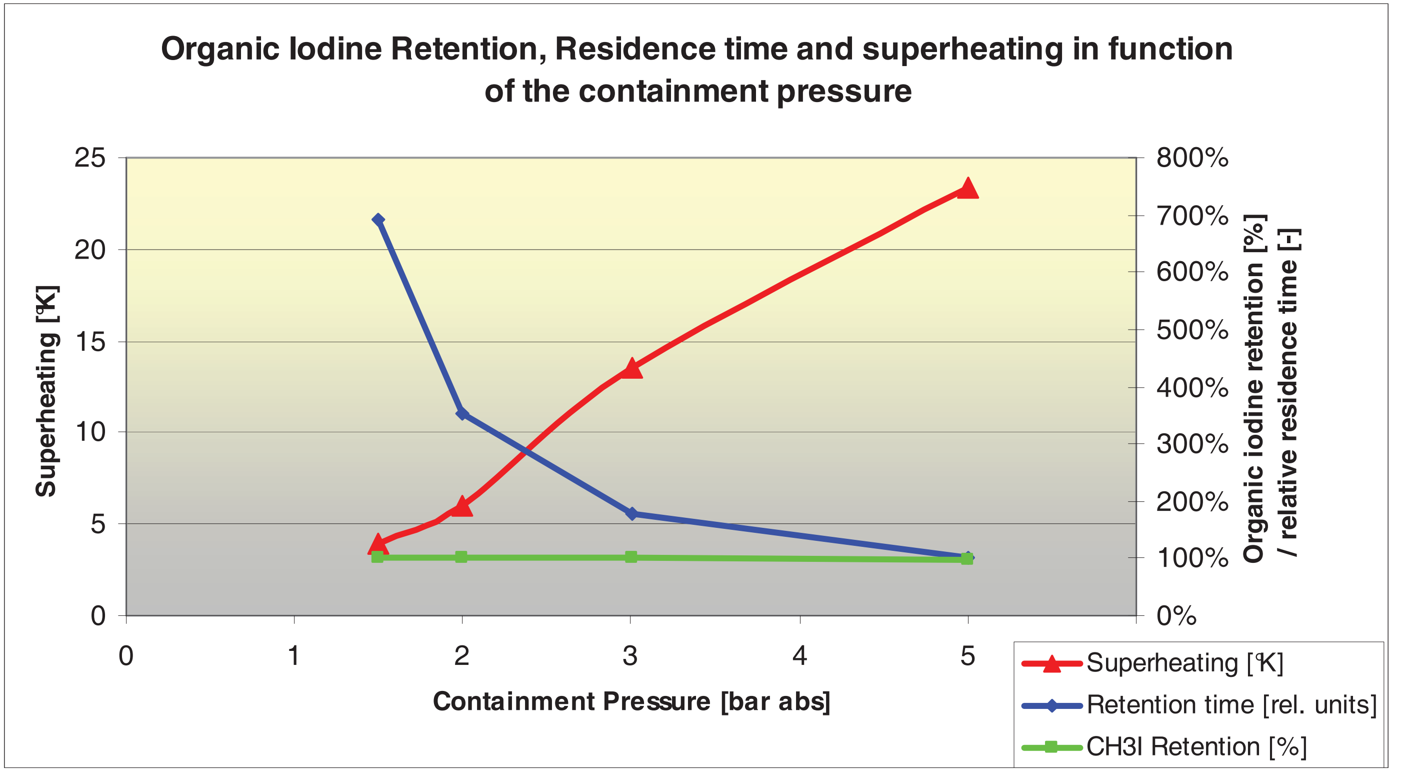


Abbildung 10.1: Zeolith-Strukturen: (a) Sodalith-Käfig; (b) A Zeolith; (c) X, Y Zeolith.

Molecular Sieve

- Retaining of remaining and re-volatilized iodine (Elemental & Organic) at the molecular sieve
- Very large reaction surface provided by the Xeolith
- Adsorption / Chemisorption
  Silver reacts coating reacts finally with iodine (I2, CH3I, etc.)
- Superheated conditions are passively provided to avoid steam condensation and clogging of reaction surface

High Speed Sliding Pressure Venting Plus



High Speed Sliding Pressure Venting Plus
Decontamination Factors (DF)

DF for Aerosols:

- Fine Aerosols > 10.000
- Large Aerosols > 100.000

DF for Iodine

- Aerosol Iodine > 1.000.000

Under Verification:

- Elemental Iodine > 1000
- Organic Iodine > 50 to 100

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Qualification

Containment Venting

Qualification programs

- **National Test Series: JAVA Tests**
- **International Test Series: ACE Filter Tests**

ACE/JAVA/IPSN/etc.
Tests and Enveloping Test Conditions

Process testing under standardized conditions, simulation of e.g.

- **Large mixed aerosol situation (for early venting situation)**
  - simulation of core melt aerosol mixture (incl. Cs, I, CsOH, $BaSO_4$, SnO_2…etc..)
- **Penetrating fine aerosols (for simulation of late venting situation)**
  - DOP/Uranin, SnO_2, etc. tests
- **Resuspension / Re-entrainment tests (simulation of effects of long term operation)**
  - with soluble and insoluble aerosols
- **Simulation of high aerosol loads/ clogging test**
- **High pressure and Temperature, etc. operation**
- **EDF/ISPN (Hydroscopic and non hydroscopic aerosols loading; incl. CsOH melt point =273°C)**

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International Venting Testing (ACE)

ACE Tests

International Programs ACE

- **International test program focused on the most environmental important <u>aerosol retention</u> and <u>re-suspension</u> issue as well as iodine.**

- **Program discussed in the ACE community under the participation of**
  - **many authorities and various research institutes and**
  - **various filtering process experts**
  - **Several commercial designer of FCVS**

- **Enveloping standardized test conditions have been extensively discussed and were finally agreed by all participants.**

- **<u>Outreach / Relevance</u>: This extensive, most representative program represents still the state of the art for aerosol & re-suspension testing.**

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ACE
Various Retention Process Investigation

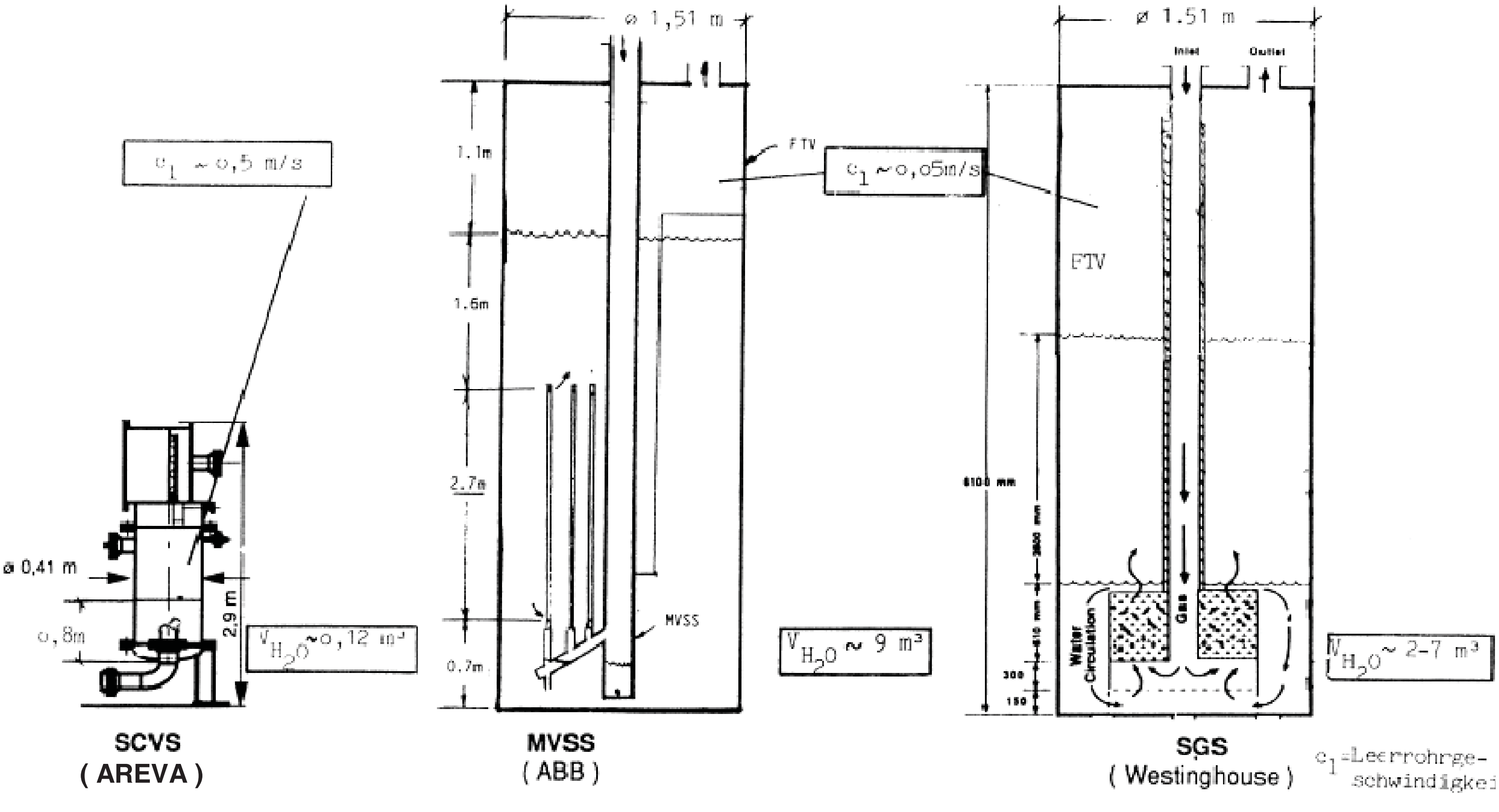
- **Dry filter system technologies tested:**
  - **Gravel bed**
  - **Sand bed filtering (US design)**
  - **Metal fibers**

- **Wet scrubbing technologies (incl. submerged internals) tested:**
  - **Submerged Gravel Bed (mixing elements)**
  - **Speed controlled multi venturi process**
  - **Combined venturi scrubber technology**
  - **Jet scrubber & sorbents**

General Results:

The identified individual process features and limits varied very significantly!

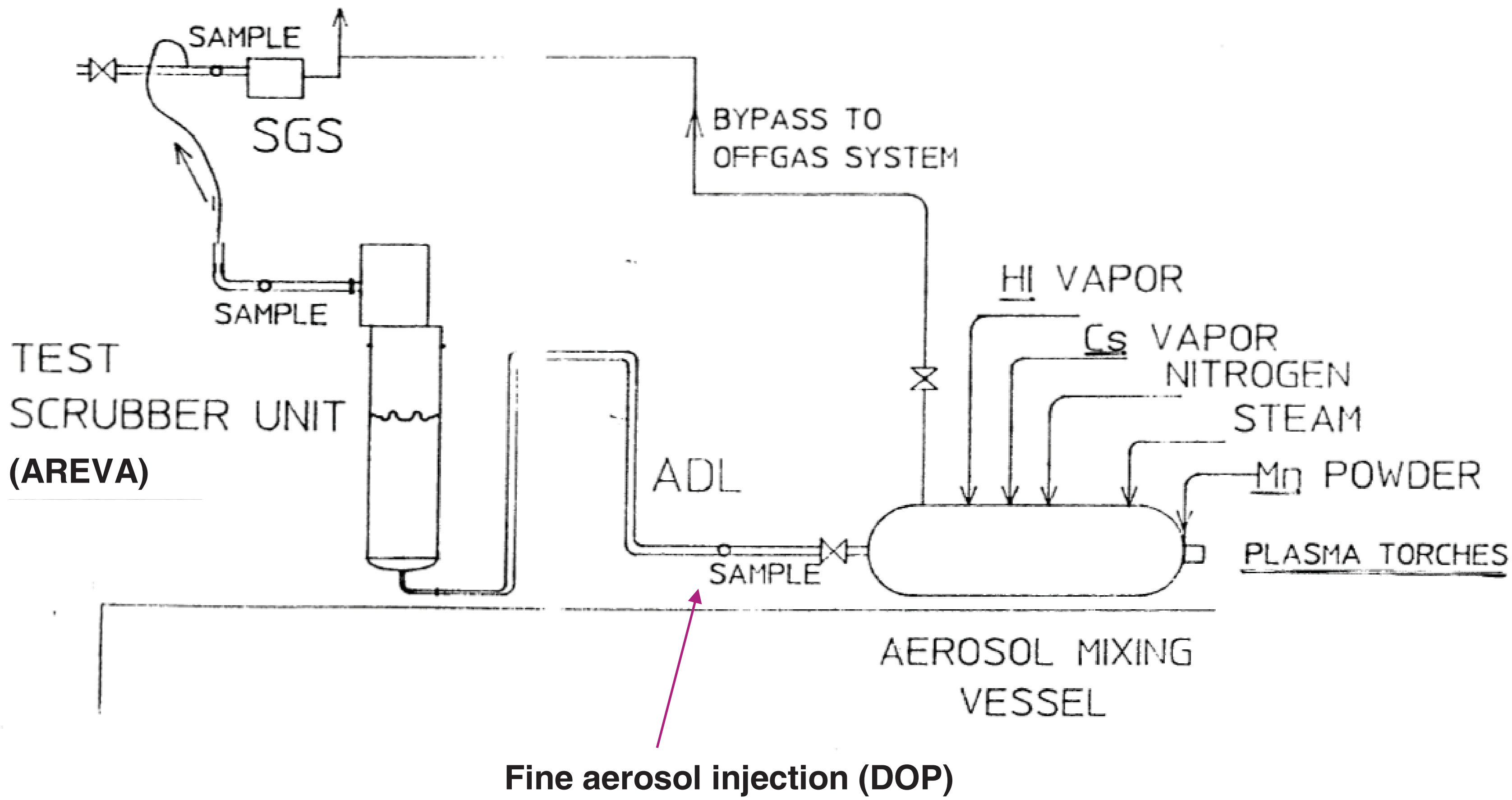
Northwest
Test vessel dimensions (equal flow rates)



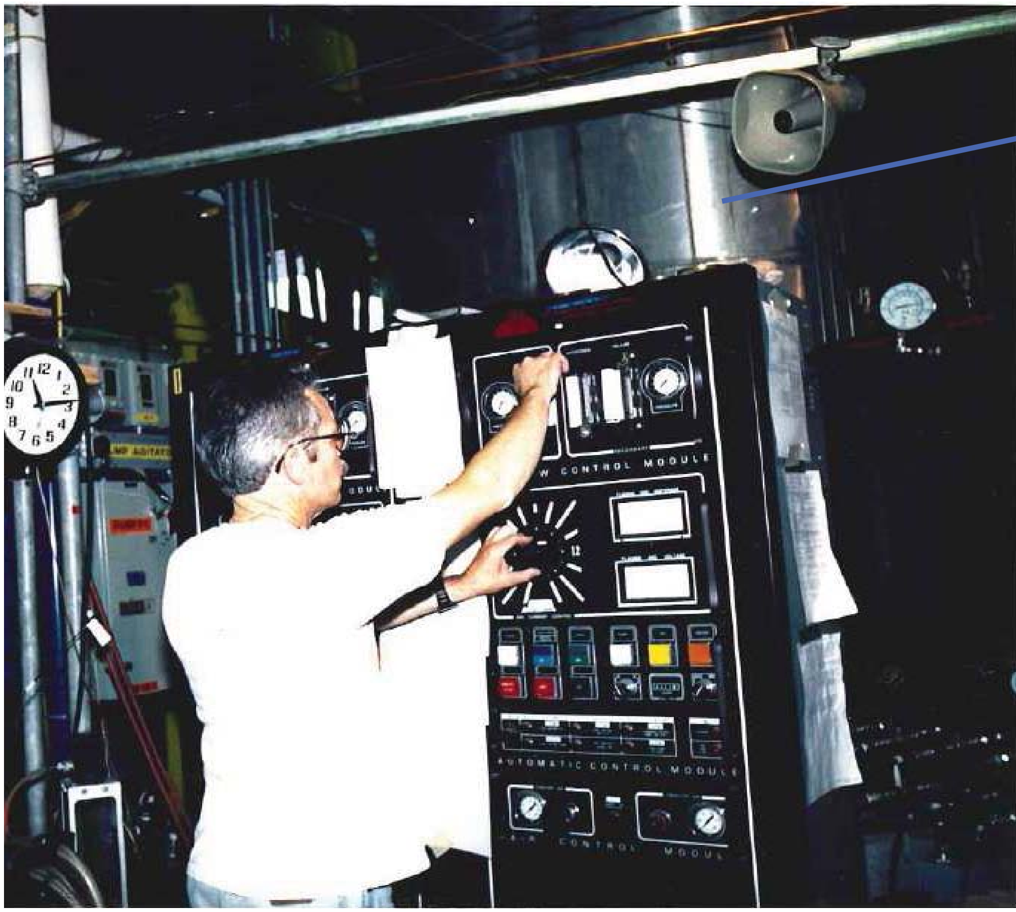
No Test Participation

Sulzer/CCI/IMI

ACE - Filter Tests at Battelle Northwest



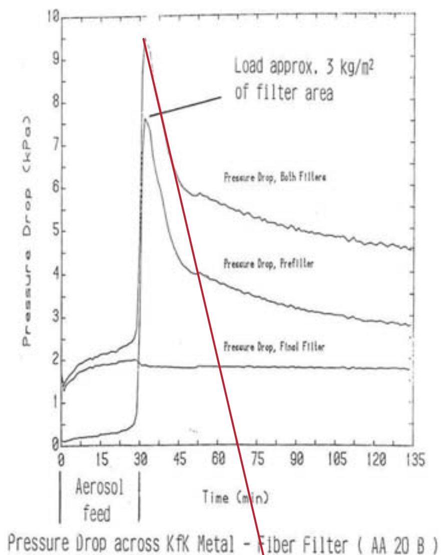
Example:AREVA Combined Scrubber at the ACE Test



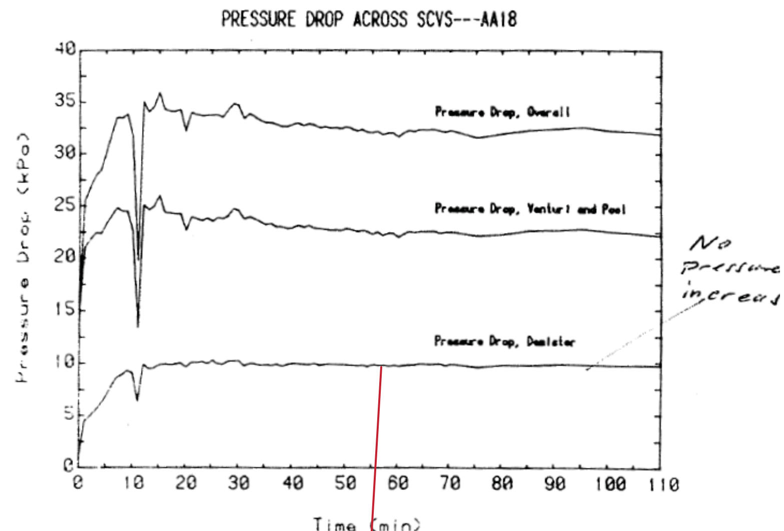
AREVA
Test Scrubber

Dry Filtration and Combined Venturi Scrubber

ACE - Filter Tests at Battelle Northwest



Dry filter



Combined Venturi Scubber (Venturi & MFF)

Filter clogging metal fibre filter observed (General issue: Preferred retention at certain layers)

No pressure increase at all at metal fibre filter inside combined venturi

ACE - Filter Tests at Battelle Northwest Results: AREVA Combined Venturi Scrubber

Extract of :

ACE-TR-A12

EXPERIMENTAL RESULTS OF ACE VENT FILTRATION:

SIEMENS COMBINED VENTURI SCRUBBER TESTS

April 1990

J. D. McCormack
D. R. Dickinson
Westinghouse Hanford Company

R. T. Allemann
Battelle, Pacific Northwest Laboratories

Table 6-12
DECONTAMINATION FACTORS FOR SCVS

	AA17	AA18
Venturi Tube	"long"	"short"
Inlet AMMD (μm)		
Cs	1.80	1.88
Mn	1.75	2.10
I	1.97	2.24
Decontamination Factor		
Cs	1.4×10^6	0.9×10^6
Mn	$>10^6$	$>0.3 \times 10^6$
I (Total)	0.3×10^6	0.3×10^6
I (Particulate)	$>3 \times 10^6$	$>3 \times 10^6$

The following observations may be made concerning the DFs:

- The DFs are all very high (on the order of 10^6), indicating a very high efficiency of the SCVS.
- All DFs were based on measurements of very low outlet concentrations which were subject to uncertainty. Significance should not be attached to differences in DF less than a factor of 2.
- No significant differences were noted between Test AA17 with the "long" venturi tube and Test AA18 with the "short" tube.
- The DF for total iodine was lower than for cesium or manganese because some iodine was present in gaseous form. The DF for particulate iodine (excluding that captured on the charcoal filter) was at least as high as that for cesium or manganese.
- Only lower limits on the DF for manganese are possible because of the uncertainties in the low values of the measured mass of manganese, as noted in Section 6.2.2.

A DF for the venturi scrubber plus pool (exclusive of the demister) may be calculated as the aerosol fed to the SCVS divided by that retained in the demister. This DF is 400 for cesium, 150 for manganese, and 300 for iodine. These are overall values for the two tests.

▶**In the official ACE report the evaluation of the combined venturi scrubber, based on the obtained experimental results for retention and resuspension, were summarized as follows:**

"All DFs were very high, on the order of 106, indicating excellent aerosol removal…"

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General Results of Filter Testing

Conclusion ACE Tests

- **Dry Filter Design:**
  - **Very high retention rates (some technologies only)**
  - **Limited loading capacities for aerosol**

- **Issues to be solved:**
  - **Critical mixed aerosol behavior and pressure operation**
  - **Very limited decay heat removal capacity**

Remark: See ongoing international discussion on aerosol & and decay heat values, plus safety margin

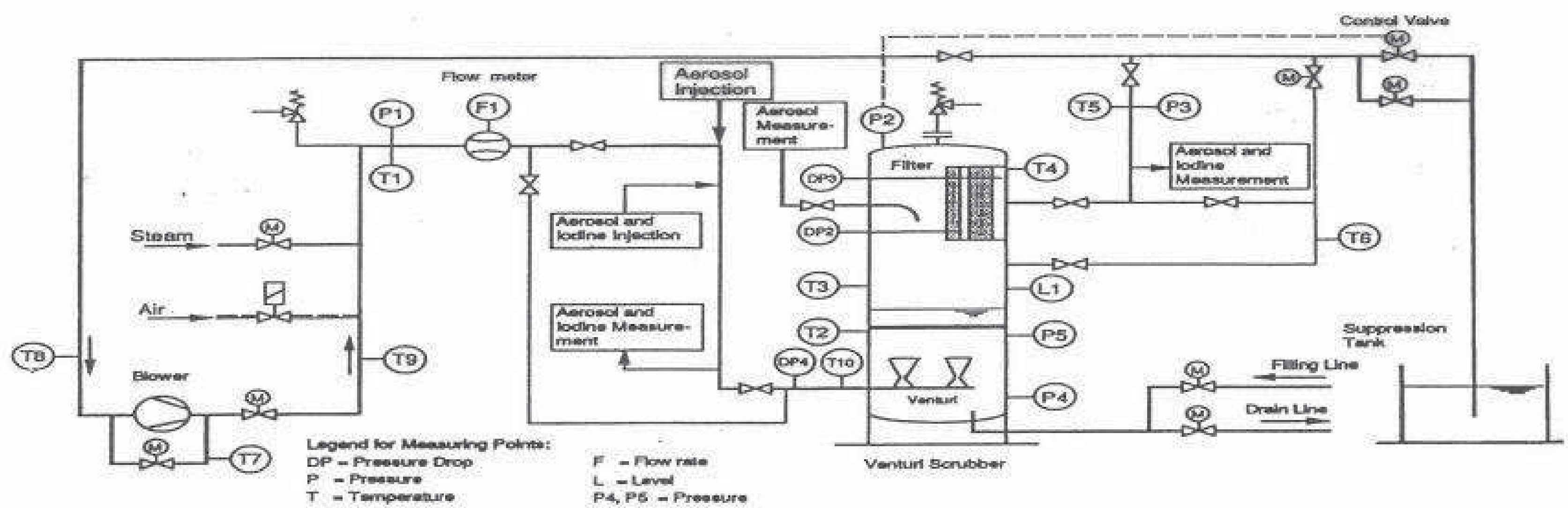
ACE Results Scrubbers

- **All <u>scrubbers</u> demonstrated**
  - **very high loading capacity for aerosols**
  - **high retention for large mixed aerosol (AMMD > 1 µm)**
  - **medium/low for fine aerosols (AMMD app. 0.5 µm)**

- **Combined Venturi Scrubber-Filter**
  - **high loading capacity for all types of aerosols**
  - **high retention for large AND fine aerosols**
  - **High compactness**

Iodine and Aerosol Retention Testing (JAVA)

JAVA – Large Test Facility and Test Parameter



Test Parameters

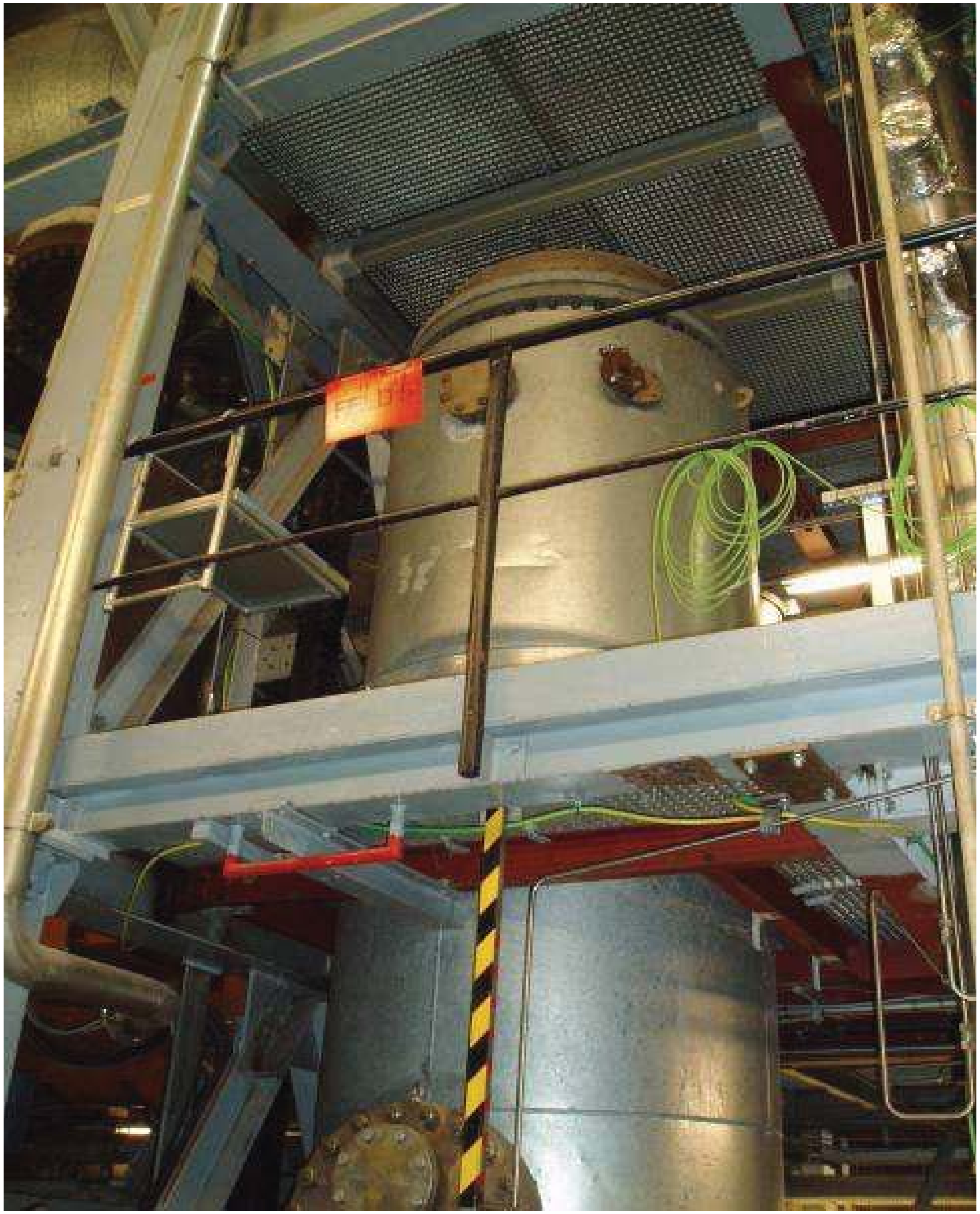
Pressure	1 – 10 bar
Temperature	50 – 200°C
Flowrate	300 – 3.000 m^3 / h
Mass flow	0.05 – 4.0 kg/s
Carrier gas	Air / steam
Aerosol concentration	SnO_2 0.1 – 0.6 g / m^3 $BaSO_4$ 0.1 – 0.6 g / m^3
Uranine	≤ 0.001 g / m^3
Iodine	Elemental Iodine (I-123 tracer)

Operating Modes

Steady-state recirculation operation

Steady-state once-through operation

Transient once-through operation (start-up simulation)

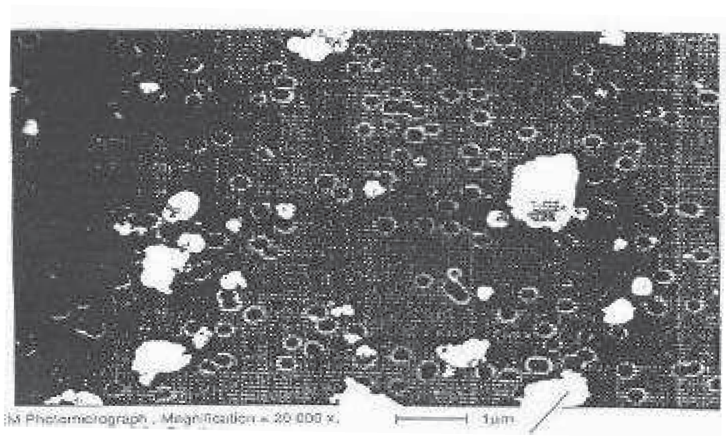


JAVA

JAVA Test Facility located at AREVAs Technical Center in Karlstein (Germany)

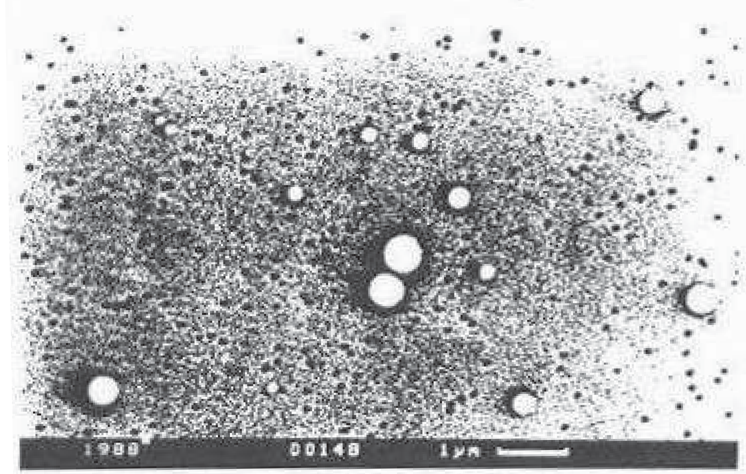
JAVA - Test

Large Aerosols



For an aerosol with a larger AMMD high DFs can also reached when fine aerosols are penetrating.
[m=f (d³)]

Fine Aerosols (Uranine)



For a fine aerosol it is essential to capture as much aerosols as possible to reach a high DF.

Test with a fine aerosol fraction are essential, e.g. DOP and/or Uranine

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JAVA Test Results

Test - No.	Aerosol	Pressure (bar)	Temp. (°C)	Gas Flow (m^3 /h)	Medium	Contaminated Gas Concentration (mg / m^3)	Total Removal Efficiency (%)
091 UL	Uranine	2.4	99	1000	Air	0.795	99.999
092 UL	Uranine	2	98	600	Air	0.875	99.999
093 UL	Uranine	6	119	600	Air	1.265	99.999
095 UL	Uranine	6	107	1350	Air	0.086	99.999
096 UL	Uranine	6	116	1000	Air	0.254	99.999
104 UL	Uranine	2	99	1000	Air	0.451	99.999
105 UL	Uranine	3	105	1220	Air	0.332	99.997

Uranine Removal Efficiency
Scrubber with Short Venturi and Two- Stage Filter

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JAVA Iodine Test Results

- **Results for Elemental Iodine**

Test No.	Venturi Type	Scrubbing Water (ph)	Pressure (bar)	Volume Flow (m^3/h)	Medium	Removal Efficiency (%)
142 JD	Short	12,7	4	1000	Steam	99,8
143 JD	Short	12,7	6	1000	Steam	99,9
144 JD	Short	12,7	6	1300	Steam	99,9
903 JD – D	Short	9,6	4,3	1200	Steam (Air+CO_2)	99,8
905 JD – D	Short	9,5	1,9	450	Steam (Air+CO_2)	99,9
910 JD – D	Long	9,3	1,8	2000	Steam (Air+CO_2)	99,9
912 JD – D	Long	9,1	1,8	1000	Steam (Air+CO_2)	99,9
913 JD – D	Long	8,9	1,8	450	Steam (Air+CO_2)	99,9

Qualification and Verification of AREVA´s

High Speed Sliding Pressure Venting Plus

Organic Iodine Retention Test Facilities

- **Small Scale Test Facility**
  (Optimisation and Qualification of Sorbents)

- **Large Scale Prototype Test Facility**
  (Verification tests of real process section)

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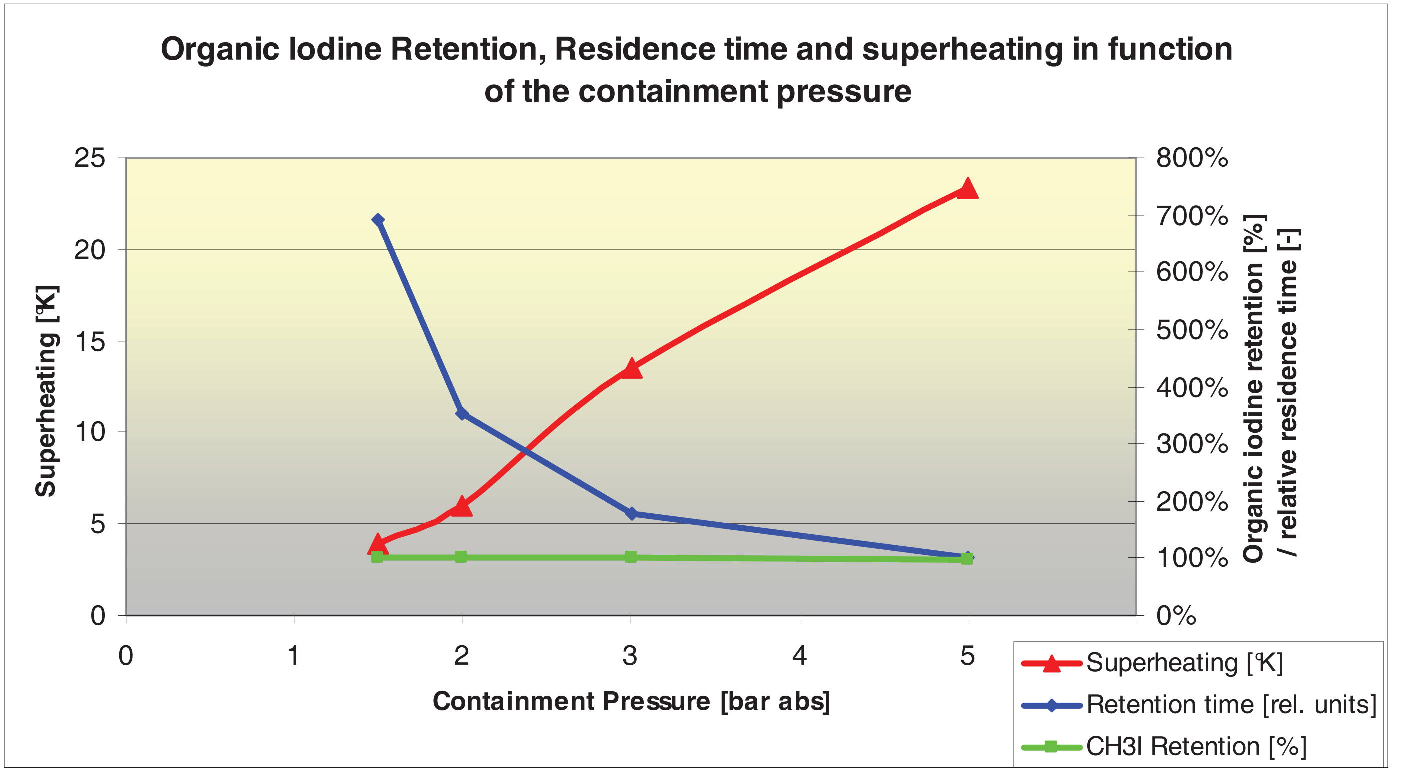
Molecular Sieve Test Facility Organic Iodine Retention Test

High Speed Sliding Pressure Venting Plus



Final Process Verification

Full Scale Prototype Test Facility

JAVA Plus

JAVA Plus Task

Verification at full scale prototype test of

- a real iodine retention process section (1 /10)

  and

- super heated by isenthalpic throttling…. in the full operating range of 1 to 10 bar

- **Verification**
  - of the real process design section in terms of
    - Reliable superheated conditions
    - Reliable long term operation
    - Total process CH_3I retention of the revalorization values
    - etc.

Sorbents stage Installed at JAVA Plus

Status

- **Sorbents qualification performed**
  - **Results show very efficient organic iodine retention of > 95 to 99%**

- **Verification tests**
  - **Large scale Prototype Test Facility under final erection**
    - **Start of tests 08.2012**
    - **End of tests 12.2012**

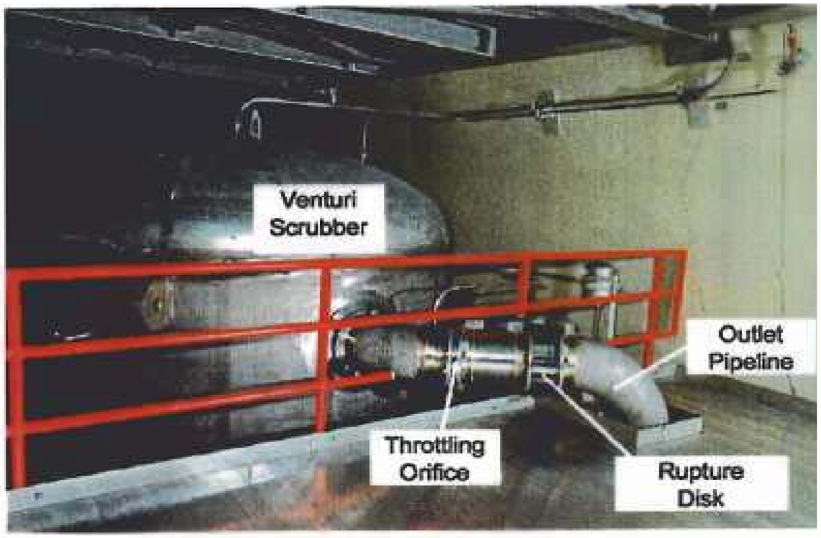
Based on the already obtained results AREVA offered

- **Organic iodine retention** **> 98 – 99%**
- **Resuspension issue** negligible, because the chemical reaction to AgI

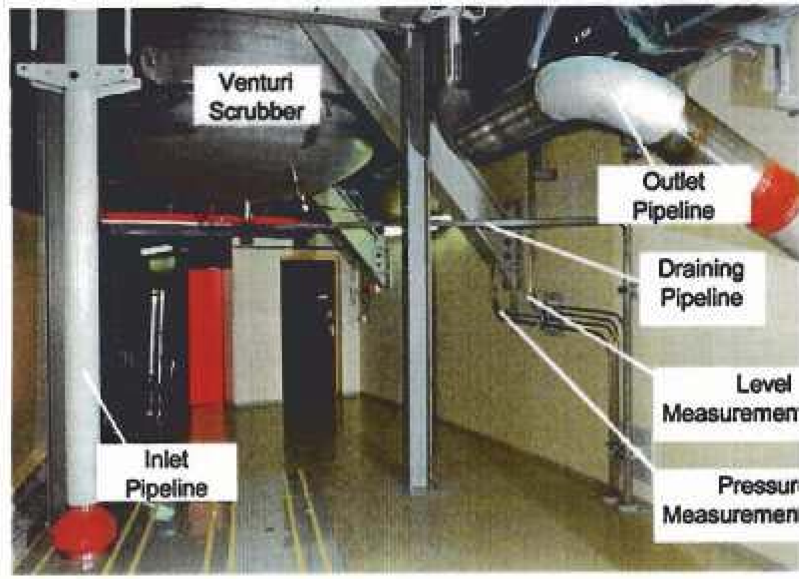
- **Costumer and authority participation during process verification possible**

Point Lepreau
Scrubber Set on Supports

Installation Examples



Upper Part of Venturi Scrubber



Lower Part of Venturi Scrubber

NPP Gösgen, Switzerland

Installation Examples

Backfitting of Venturi Scrubber Unit had required cutting of outer shell of auxiliary building (thickness 1300 mm)

Containment Filtered Venting System
Metal Fibre Filter Section

AREVA

Metal Fibre Filter Modules CPR1000 Series

References
AREVA Filtered Containment Venting

Country	Name	Type	Status	Since
Germany	Krümmel	BWR	operable	12/1987
	Brunsbüttel	BWR	operable	06/1988
	Philippsburg 1	BWR	operable	02/1990
	Würgassen	BWR	delivered	08/1989
	Isar 1	BWR	operable	04/1989
	Gundremmingen B	BWR	operable	12/1990
	Gundremmingen C	BWR	operable	12/1990
	Philippsburg 2	PWR	operable	09/1990
	Grafenrheinfeld	PWR	operable	12/1992
	Obrigheim	PWR	operable	06/1991
	Neckar 1	PWR	operable	06/1992
	Neckar 2	PWR	operable	07/1990
	Isar 2	PWR	operable	03/1991
	Emsland	PWR	operable	03/1991
Finland	Teollisuuden 1 (TVO 1)	BWR	operable	11/1989
	Teollisuuden 2 (TVO 2)	BWR	operable	11/1989
	Olkiluoto 3	PWR	delivered	12/2009
Switzerland	Gösgen	PWR	operable	12/1993
Netherlands	Borssele	PWR	operable	06/1997
Bulgaria	Kozloduy 5	VVER 1000	operable	08/2004
	Kozloduy 6	VVER 1000	operable	08/2005
	Kozloduy 3	VVER 440	operable	04/2005
	Kozloduy 4	VVER 440	operable	04/2005
Romania	Cernavoda1	HPWR	under construction	01/2012
	Cernavoda2	HPWR	under construction	01/2012
Canada	Point Lepreau	HPWR	delivered	08/2008
	Gentilly	HPWR	delivered	07/2010

Country	Name	Type	Status	Since
P. R. China	Qinshan Phase 2 Unit 1	PWR	operable	12/2006
	Qinshan Phase 2 Unit 2	PWR	operable	12/2006
	Ling Ao Phase 2 Unit 3	PWR	operable	07/2010
	Ling Ao Phase 2 Unit 4	PWR	operable	07/2010
	Qinshan Phase 2 Unit 3	PWR	operable	07/2010
	Qinshan Phase 2 Unit 4	PWR	operable	07/2010
	Hongyanhe Phase I Unit 1	PWR	delivered	12/2010
	Hongyanhe Phase I Unit 2	PWR	delivered	12/2010
	Ningde Phase I Unit 1	PWR	delivered	02/2011
	Ningde Phase I Unit 2	PWR	delivered	02/2011
	Yangjiang Phase I Unit 1	PWR	delivered	10/2011
	Yangjiang Phase I Unit 2	PWR	delivered	10/2011
	Fangjiashan Phase I Unit 1	PWR	delivered	10/2011
	Fangjiashan Phase I Unit 2	PWR	delivered	10/2011
	Fuqing Phase I Unit 1	PWR	delivered	08/2011
	Fuqing Phase I Unit 2	PWR	delivered	08/2011
	Hongyanhe Phase I Unit 3	PWR	under construction	06/2009
	Hongyanhe Phase I Unit 4	PWR	under construction	06/2009
	Ningde Phase I Unit 3	PWR	under construction	06/2009
	Ningde Phase I Unit 4	PWR	under construction	06/2009
	Changjiang Phase I Unit 1	PWR	under construction	09/2009
	Changjiang Phase I Unit 2	PWR	under construction	09/2009
	Fuqing Phase I Unit 3	PWR	under construction	12/2009
	Fuqing Phase I Unit 4	PWR	under construction	12/2009
	Fangchenggang Phase I Unit 1	PWR	under construction	03/2011
	Fangchenggang Phase I Unit 2	PWR	under construction	03/2011
	Yangjiang Phase I Unit 3	PWR	under construction	03/2011
	Yangjiang Phase I Unit 4	PWR	under construction	03/2011

During the last 10 years AREVA technology has been retrofitted to 37 reactor units

AREVA